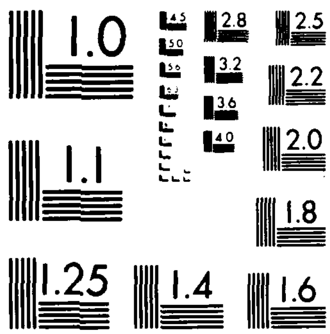
AD-A184 199 ASPHALT HOT-MIX RECYCLING(U) FLORIDA UNIV GAINESVILLE 1/2
D L WATTS 1987 N00228-85-G-3323

UNCLASSIFIED F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ASPHALT HOT-MIX RECYCLING

N-00228-85-G-3323

BY

DAVID L. WATTS

UNIVERSITY OF FLORIDA

SUMMER 1987

ASPHALT HOT-MIX RECYCLING

BY

DAVID L. WATTS

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

SUMMER 1987

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Flexible pavement recycling can be broken down into the major categories of surface, cold-mix, and hot-mix recycling. This report will only deal with asphalt hot-mix recycling. The main factors which go into determining the selection, design, quality control, construction, and economics of the asphalt hot-mix process will be presented.

Asphalt hot-mix recycling as used in this report has been defined by The Asphalt Institute as:

> A process in which reclaimed asphalt pavement (RAP) materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as necessary, in a central plant to produce hot-mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced. [1]

Although the idea of hot-mix recycling is not new, it took the oil embargo of 1973 to dramatically point out that there was not an unlimited supply of inexpensive asphalt materials. Additionally, the availability of high quality aggregate was becoming limited in many areas. This limited availability as well as rapidly increasing fuel prices for excavation, crushing, and hauling, was driving up the cost of aggregate. These factors combined to form the catalyst

---

1. The Asphalt Institute, <u>Asphalt Hot-Mix Recycling (MS-20)</u>, 2nd ed. (The Asphalt Institute, College Park, Md. 1986), p. 1.

needed to spur the development of standardized asphalt hot-mix recycling procedures.

As could be expected, the initial use of recycled materials was on a small scale, since the technology and construction equipment for recycling pavements had not been sufficiently developed. By the early 1980's, much work had been done in the area to develop the technology and construction equipment to the point that asphalt hot-mix recycling was becoming an established and accepted procedure.

Asphalt hot-mix recycling must be looked upon as one of many choices in the overall maintenance/rehabilitation of a flexible pavement. For this reason, the advantages and disadvantages of asphalt hot-mix recycling must be kept in mind by the engineer making the choice of maintenance/rehabilitation methods. Chapter two will present the major factors which the engineer will need to keep in mind when making this decision.

Chapter three will then outline the requirements for the evaluation of the materials being considered for use in the recycling project. The first major consideration in this evaluation process is the method for choosing representative samples of the materials. Past construction records must be reviewed for material composition, layer thicknesses, widths, and lengths, and number of lanes. With this information, the proposed project site should be divided into sections for sampling purposes. One of the most effective sampling methods devised is random sampling based on a table of random numbers. The properties of these samples must then be tested in the laboratory. It should be expected that in general, asphalt pavements which are candidates for recycling, can have a comparatively high level of variability.

Chapter four will then present the mix design procedure as advocated by The Asphalt Institute. This mix design procedure uses either the Marshall or the Hveem method. This chapter will then present an outline of how both the Florida Department of Transportation (FDOT) and the Wisconsin Department of Transportation (WisDOT) are currently handling asphalt hot-mix recycling design.

In chapter five, a view of an actual FDOT hot-mix recycling project will be presented. This will include looking at the initial Composition of Existing Pavement, initial job-mix formula, quality control criteria and following the various changes in the job-mix formula throughout the project.

Chapter six will present an overview of the construction equipment considerations in the asphalt hot-mix recycling process. This will include the reclaiming, plant, and placing processes.

The economic factors which must be considered in the asphalt hot-mix recycling process will be presented in chapter seven. Cost is a major consideration in the use of the hot-mix recycling process. The main emphasis of this material will be the comparison of the economics of the hot-mix recycling process to the conventional asphalt overlay.

Chapter eight will then provide a conclusion for the material presented in the body of the report. It is hoped that this report will be a valuable guideline for the engineer in learning about the important factors affecting the asphalt hot-mix recycling process. Hot-mix recycling should be approached from the point of view that the final product will be equal to or better than the original mix design and that all current mix specifications are met.

CHAPTER TWO

THE ASPHALT HOT-MIX RECYCLING ALTERNATIVE

INTRODUCTION

While this report is concentrating on asphalt hot-mix recycling, in reality it should be looked upon as only one of a number of methods of rehabilitating distressed asphalt pavements. The main options to be considered are:

1. Patch
2. Patch and thin overlay
3. Patch and thick overlay
4. Reconstruct with all new materials
5. Surface recycle
6. Cold-mix recycle
7. Hot-mix recycle

The first step the engineer should take is to determine the probable cause of pavement distress. In this process, the original pavement design and construction records should be reviewed. Then field tests, including deflection and visual inspection should be performed. Laboratory tests of pavement samples should be included. All of this information should then be analyzed along with giving consideration to expected performance, environmental influences, projected traffic volume and weights, pavement geometrics, and economics, to decide the appropriate rehabilitation method.

This chapter will deal with the advantages and disadvantages involved in the asphalt hot-mix recycling process. These items should be kept in mind by the engineer in deciding if hot-mix recycling should be chosen or not.

ADVANTAGES

The following is a list of some of the major advantages of hot-mix recycling:

1. Significant structural improvements can be made.
2. All types and degrees of pavement distress can be treated.
3. Reflection cracking can be eliminated.
4. Geometrics can be maintained or improved.
5. Ride quality can be improved.
6. Skid resistance can be improved.
7. Aggregate is conserved.
8. Asphalt cement is conserved.
9. Energy consumption is reduced.
10. Construction costs are lower than for overlays using all new materials.

If the pavement has deteriorated to the point where it has inadequate structural capacity, hot-mix recycling can restore the lost structural capacity. Also, if the current or projected traffic data show that the structural capacity of the pavement must be increased, then hot-mix recycling may be a viable alternative. The pavement would have had to show signs of distress, otherwise an overlay would be a more logical choice though.

Since hot-mix recycling involves removing the existing asphaltic concrete materials and designing a new mix, all types and degrees of pavement distress can be remedied. For instance cracks will be removed. If stripping had been a problem, anti stripping agent can be added to the recycled mix. If problems were the result of an inadequate base, then the bituminous materials would have to removed anyway to correct this situation, and recycling should be considered.

Reflective cracking can be a large problem with overlays. Hot-mix recycling will eliminate the crack rather than just covering it over. This will effectively eliminate reflective cracking.

Geometric considerations in hot-mix recycling can be very considerable. Vertical clearances can be maintained and this becomes critical in areas such as with overpasses. Curb and gutter lines can be maintained. The need to raise manholes in urban areas can be reduced as well. Hot-mix recycling also eliminates the need to adjust shoulder elevations unless the total pavement thickness is much greater than the original pavement.

A significant indication of pavement distress can be seen in the degradation of ride quality. Hot-mix recycling will restore the ride quality through elimination of ruts, cracks, etc., which degrade the ride quality.

Skid resistance can be restored to a pavement during hot-mix recycling. Additional aggregate with improved skid resistance qualities can be added to the recycled mix. Even without adding significant quantities of new aggregate, the skid resistance could be improved through reorientation of the aggregate within the mix.

The hot-mix recycling will also conserve aggregate. There are many locations where high quality aggregate is becoming increasingly scarce. Re-utilizing the aggregate already in place makes good environmental as well as economic sense.

Asphalt cement will be conserved as well. As oil prices remain high, the cost of asphalt cement will remain high as well. As with the aggregate, recycling the asphalt cement makes good environmental as well as economic sense.

The hot-mix recycling process also helps to conserve energy. The amount of energy conserved will depend on many factors. Factors such as project location, amount of RAP in the mix, plant type and configuration, etc., all play a part. These factors will be discussed in more detail in chapter seven.

The bottom line that makes hot-mix recycling so attractive is the fact that the costs are less than for overlays using all new materials. The ability to conserve aggregate, asphalt cement, and energy, all combine to reduce the total cost. The additional costs of milling or breaking up and handling the RAP do not negate all of the potential savings involved. Chapter seven will discuss the economics of hot-mix recycling in greater detail.

DISADVANTAGES

The following items can be looked upon as disadvantages or really more accurately as obstacles to the hot-mix recycling process:

1. Improved quality control is required from start to finish.

2. There are potential air pollution problems at the plant.

3. It can be difficult to keep excess moisture out of the RAP.

4. There may be a lack of qualified contractors in the area.

Quality control in the hot-mix recycling process is more involved than in conventional paving. Projects which are candidates for recycling can normally be expected to exhibit a lot of variability in materials. The material properties will show this variability for numerous reasons. Some of these are from previous maintenance which would include patches, seal coats, joint sealers etc., the project area may include the work of several original contracts to construct the road, oil droppings from cars and trucks will be on the road, and areas which exhibit bad cracking will normally have higher asphalt cement viscosities. With these problems, quality control measures have to be taken seriously. Chapter three will discuss methods of sampling the existing materials to help cope with this expected variability in material properties.

An environmental consideration which comes into play in this process is air pollution at the plant. The main problem associated with recycled mixes is the opacity of the emissions from the plant. This is mostly controlled by the design of the plant and the quantity of RAP used in the mix. This will be discussed further in chapter six.

It is fairly easy for moisture to get into the RAP material if it is not protected. When excess moisture does get into the RAP, it can lead to problems at the time of mixing. A longer time in the plant will be required to drive off the excess moisture and this can cause a large drop in productivity. This moisture will also cause the opacity to increase.

If hot-mix recycling is new to an area, there may be a problem due to the lack of experienced contractors. This also means a possible lack of proper equipment. The popularity of hot-mix recycling is such that this problem is disappearing in most parts of the country though. If it does appear to be a problem in a particular area, projects must be sufficiently large to either attract an outside contractor or to enable a local contractor to justify the purchase of the equipment. Future hot-mix recycling projects must then be developed and this information passed on to the contractors in order to maintain their interest.

CONCLUSION

Hot-mix recycling is one of many alternatives for the rehabilitation of a pavement. It is one that does have many significant advantages and few disadvantages. When choosing the appropriate alternative, the engineer must have some familiarity with all of his options. This chapter has highlighted the key advantages and disadvantages in the hot-mix recycling process. There are many sources of information concerning the other alternatives. The Asphalt Institute is an excellent source of this information.

The advantages of hot-mix recycling have lead to a tremendous increase in the acceptance and use of this alternative. While it is clearly not the appropriate choice of alternatives in all situations, there are a significant number of projects which could benefit from it. It is hoped that the information presented in this and subsequent chapters will help the engineer to understand more about this key alternative and allow him to choose it appropriately.

CHAPTER THREE

EVALUATION OF MATERIALS

INTRODUCTION

It should be expected that in general, asphalt pavements which are candidates for recycling, can have a comparatively high level of variability. With this in mind, the methods chosen for obtaining representative samples of the existing materials, become very important. This chapter will present a random sampling method which has proven effective on actual hot-mix recycling projects.

Once representative samples of the reclaimed asphalt pavement (RAP) have been obtained, the composition must be determined. This should include:

1. Aggregate gradation
2. Asphalt content
3. Asphalt viscosity at 60 deg C (140 deg F)

and/or asphalt penetration at 25 deg C (77 deg F)

It should be noted that the crushing or milling of the RAP will alter the gradation of the aggregate (increase the percentage of fines). Therefore, samples tested should be representative of the cold feed stock piles at the plant site. Some states including Florida, have developed a table of factors to convert the gradation of the existing pavement to the gradation which will exist after milling. This table will be presented, but would only be valid for the normal aggregate used in Florida. It still only provides an approximation though.

Samples of the possible new asphalt and/or recycling agents and new aggregate should be at hand. These samples along with the data obtained from the existing materials will form the basis for the mix design.

RANDOM SAMPLING PROCEDURES

Since variability is to be expected in the recycling project, one of the most effective sampling procedures is known as random sampling. For a hot-mix recycling project, four types of sampling plans are possible. These are for sampling in-place pavements, milled or processed RAP from trucks, stockpiles of RAP using power equipment, and stockpiles of RAP without using power equipment. The procedures outlined below for each of these plans, are based on the plans developed, tested, and presented in The Asphalt Institute Research Report No. 84-2.

PLAN FOR SAMPLING PAVEMENTS IN PLACE

1. Investigate construction and maintenance records and determine as nearly as possible the composition of the pavement along the roadway to be recycled. Separate the pavement into construction units that have similar composition.

2. If the construction unit is two lanes wide, divide each construction unit into six to eight sections of equal length. Randomly select one sampling location in each lane of each section.

3. If the construction unit is only one lane wide, divide the length into 12 to 16 subsections of equal length and select one random sampling location in each section.

4. Obtain one sample of pavement at each sampling location of sufficient size, at least 15 pounds, for extraction and recovery testing. There should be 12 to 16 samples or more to be tested individually for each construction unit.

PLAN FOR SAMPLING MILLED OR PROCESSED RAP FROM TRUCKS

1. Investigate construction and maintenance records and determine as closely as possible the composition of the pavement along the roadway to be recycled. Separate the pavement into construction units that have similar composition.

2. Divide the production into 12 to 16 (one or two day) time periods. Randomly select two trucks from each time period for sampling. If a production day is less than half a work day, include with next half or full day.

3. Obtain one sample of RAP from each truck of sufficient size, at least 15 pounds, for an extraction and recovery test and for possible use in mix design. There

should be a total of 12 to 16 or more samples to be tested individually for each construction unit.

PLAN FOR SAMPLING STOCKPILES OF RAP USING POWER EQUIPMENT

1. Investigate records of the owner of an existing stockpile to obtain information about the source and composition of the material in the stockpile.

2. If the stockpile consists of unprocessed slabs, or has been sitting for a long time, it may be necessary to process the material before sampling.

3. If the material appears to be uniform in composition and from one source, proceed to step 6.

4. If the material is from different sources, if sources cannot be identified, or if the material appears to be of different composition:

A. Thoroughly mix or reprocess the stockpile into one uniform lot, or

B. Separate the stockpile into uniform-appearing lots and treat as separate stockpiles.

5. Since appearance alone cannot guarantee uniformity, the stockpile should be sampled in such a way as to enable non-uniformity to be detected.

6. Using a rectangular grid-pattern, divide the stockpile into blocks of approximately 2,000 tons each. The blocks and grid pattern need not be square or rectangular shapes, but blocks should cover approximately the same area

or quantity of material. A minimum of 12 to 16 blocks should be selected.

7. Number the blocks in a regular manner.

8. Select X - Y coordinates for the sampling point in each block using a random number procedure. This may be done by selecting two random numbers from 0.1 to 1.0 and multiplying them times the length of the X and Y sides of the blocks to locate the coordinates in feet. Use the same relative origin in each block.

9. If peaks or valleys occur in the stockpile to such an extent that the normal sampling plan is not effective, then either rework the stockpile or modify the sampling plan. In some cases, the stockpile may be subdivided into smaller lots. In others, substitute random samples from a higher level for samples that would be located where there is a valley.

10. Using a front-end loader, obtain approximately 1 ton of material from each randomly selected location in the section at the upper third level and one similar sample from the lower third level of the stockpile. Record the location of each sample.

11. Using the method of quartering or a large sample splitter, reduce each one ton sample to a sample of sufficient size, at least 15 pounds, for extraction and recovery testing and for possible use in mix design.

PLAN FOR SAMPLING STOCKPILES OF RAP WITHOUT POWER EQUIPMENT

1. through 8. - Same as for with power equipment available.

9. By hand, remove one to three feet of material from the top of the pile at each sample location and carefully remove a 15 to 25 pound sample. Record block and location within the block.

10. If the stockpile is two layers in height it may be impossible to sample the interior of the bottom layer of the stockpile. Therefore, the bottom layer should be sampled from the side, using only the outer blocks. Use a new set of coordinates and locate the samples along the Y axis (X coordinate = 0), at about midheight. Cut a vertical face about two feet into the stockpile face and remove a 15 to 25 pound sample. Record block, layer number and location within the block.

SELECTING SAMPLING LOCATIONS

The preceding sampling procedures require the selection of an actual sampling location to be random. There are many ways in which this could be done. The following method was the one used in The Asphalt Institute Research Report No. 84-2, for the hot-mix recycling projects it studied.

SAMPLING FROM THE ROADWAY

1. Designate sections or blocks as specified in the sampling procedure being used.

2. Determine the number of sampling locations within a section as specified in the sampling procedure being used.

3. Select a column of random numbers in Table 1 by placing 28 pieces of cardboard 1 inch square, numbered 1 through 28, into a container, shaking them so that they become thoroughly mixed and drawing one out.

4. Go to the column of random numbers identified by the number drawn from the container. In subcolumn A, locate all numbers equal to or less than the number of sampling locations per section desired.

5. Multiply the total length of the section by the decimal values in subcolumn B, found opposite the numbers located in subcolumn A. Add the result to the station number at the beginning of the section to obtain the station of the sampling location.

6. Multiply the total width of the lane (or lanes) in the section by the decimal values in subcolumn C, found opposite the numbers located in subcolumn A. These are the offset distances from the pavement centerline at which the samples are to be taken.

7. Repeat the procedure for each section.

TABLE 1 - RANDOM NUMBERS FOR GENERAL SAMPLING PROCEDURES

(FROM THE ASPHALT INSTITUTE RR-84-2)

Col No 1			Col No 2			Col No 3			Col No 4			Col No 5			Col No 6			Col No 7		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
15	033	576	05	048	879	21	013	220	18	089	716	17	024	863	30	030	901	12	029	386
21	101	300	17	074	156	30	036	853	10	102	330	24	060	032	21	096	198	18	112	284
23	129	916	18	102	191	10	052	746	14	111	925	26	074	639	10	100	141	20	114	848
30	158	434	06	105	257	25	061	954	28	127	840	07	167	512	29	133	388	03	121	656
24	177	397	28	179	447	29	062	507	24	132	271	28	194	776	24	138	062	13	178	640
11	202	271	26	187	844	18	087	887	19	285	899	03	219	166	20	168	564	22	209	421
16	204	012	04	188	482	24	105	849	01	326	037	29	264	284	22	232	953	16	221	311
08	208	418	02	208	577	07	139	159	30	334	938	11	282	262	14	259	217	29	235	356
19	211	798	03	214	402	01	175	641	22	405	295	14	379	994	01	275	195	28	264	941
29	233	070	07	245	080	23	196	873	05	421	282	13	394	405	06	277	475	11	287	199
07	260	073	13	248	831	26	240	981	13	451	212	06	410	157	02	296	497	02	336	992
17	262	308	29	261	087	14	255	374	02	461	023	15	438	700	26	311	144	15	393	488
23	271	180	30	302	883	06	310	043	06	487	539	22	453	635	05	331	141	19	437	655
06	302	672	21	318	088	11	316	653	08	497	396	21	472	824	17	370	811	24	466	773
01	409	406	11	376	936	13	324	585	25	503	893	05	488	118	09	388	484	14	531	014
13	507	693	14	430	814	12	351	275	15	594	603	01	525	222	04	410	073	09	562	678
02	575	654	27	438	676	20	371	535	27	620	894	12	561	980	25	471	530	06	601	675
18	591	318	08	447	205	08	409	495	21	629	841	08	652	508	13	486	779	10	612	859
20	610	821	09	474	138	16	445	740	17	691	583	18	668	271	15	515	867	26	673	112
12	631	597	10	492	474	03	494	929	09	708	689	30	736	634	23	567	798	23	738	770
27	651	281	13	499	892	27	543	387	07	709	012	02	763	253	11	618	502	21	753	614
04	661	953	19	511	520	17	625	171	11	714	049	23	804	140	28	636	148	30	758	851
22	692	089	23	591	770	02	699	073	23	720	695	25	828	425	27	650	741	27	765	563
05	779	346	20	604	730	19	702	934	03	748	413	10	843	627	16	711	508	07	780	534
09	787	173	24	654	330	22	816	802	20	781	603	16	858	849	19	778	812	04	818	187
10	818	837	12	728	523	04	838	166	26	830	384	04	903	327	07	804	675	17	837	353
14	895	631	16	753	344	15	904	116	04	843	007	09	912	382	08	806	952	05	854	818
26	912	376	01	806	134	28	969	742	12	884	582	27	935	162	18	841	414	01	867	133
28	920	163	22	878	884	09	974	046	29	926	700	20	970	582	12	918	114	08	915	538
03	945	140	25	939	162	05	977	494	16	951	601	19	975	437	03	992	399	25	975	284

Col No 8			Col No 9			Col No 10			Col No 11			Col No 12			Col No 13			Col No 14		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
09	042	071	14	061	935	26	038	023	27	074	779	16	073	987	03	033	091	26	035	175
17	141	411	02	065	097	30	066	371	06	084	396	23	078	056	07	047	391	17	089	363
02	143	221	03	094	228	27	073	876	24	098	524	17	096	076	28	064	113	10	149	681
05	162	899	16	122	945	09	095	568	10	133	919	04	153	163	12	066	360	28	238	075
03	285	016	18	158	430	05	180	741	15	187	079	10	254	834	26	076	552	13	244	767
28	291	034	25	193	469	12	200	851	17	227	767	06	284	628	30	087	101	24	262	366
08	369	557	24	224	572	13	259	327	20	236	571	12	305	616	02	127	187	08	264	651
01	436	386	10	225	223	21	264	681	01	245	988	25	319	901	06	144	068	18	285	311
20	450	289	09	233	838	17	283	645	04	317	291	01	320	212	25	207	674	02	340	131
18	455	789	20	290	170	23	363	063	29	350	911	08	414	372	01	247	025	29	353	478
23	488	715	01	297	242	20	364	366	26	380	104	13	432	556	23	253	323	06	359	270
14	496	276	11	337	760	16	395	363	28	425	864	02	489	827	24	320	651	20	387	248
15	503	342	19	389	064	02	423	540	22	487	576	29	503	787	10	328	365	14	372	694
04	515	693	13	411	474	08	432	736	05	552	511	15	518	717	27	338	412	03	408	077
16	532	112	20	447	893	10	476	468	14	564	357	28	524	998	13	356	991	27	440	280
22	557	337	22	478	321	03	508	774	11	572	306	03	542	352	16	401	792	22	441	830
11	559	620	29	481	993	01	601	417	21	594	197	19	585	462	17	423	117	16	527	003
12	650	216	27	562	403	22	687	917	09	607	524	05	695	111	21	481	838	30	531	486
21	672	320	04	566	179	29	697	862	19	650	572	07	733	838	08	560	401	25	678	360
13	709	273	08	603	758	11	701	605	18	664	101	11	744	948	19	564	190	21	725	014
07	745	687	15	632	927	07	728	498	25	674	428	18	793	748	05	571	054	05	797	595
30	780	285	06	707	107	14	745	679	02	697	674	27	802	967	18	587	584	15	801	927
19	845	097	28	737	161	24	819	444	03	767	928	21	826	487	15	604	145	12	836	294
26	846	366	17	846	130	15	840	823	16	809	529	24	835	832	11	641	298	04	854	982
29	861	307	07	874	491	23	863	568	30	838	294	26	855	142	22	672	156	11	884	928
25	906	874	05	880	878	06	878	315	13	845	470	14	861	462	20	674	887	19	886	832
24	919	809	23	931	639	18	930	601	08	855	524	20	874	625	14	752	881	07	929	932
10	952	555	26	960	365	04	954	837	07	867	718	30	929	056	09	774	560	09	932	206
06	961	504	21	978	194	28	963	004	12	881	722	09	935	582	29	921	752	01	970	692
27	969	811	12	982	183	19	988	020	23	937	872	22	947	797	04	959	099	23	973	082

TABLE 1 (CONT.) - RANDOM NUMBERS FOR GENERAL SAMPLING PROCEDURES

Col No 15			Col No 16			Col No 17			Col No 18			Col No 19			Col No 20			Col No 21		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
15	023	979	19	062	588	13	045	004	25	027	290	12	052	075	20	030	881	01	010	946
11	118	465	25	080	218	18	086	878	06	057	571	30	075	493	12	034	291	10	014	939
07	134	172	09	131	295	26	126	990	26	059	026	28	120	341	22	043	893	09	032	346
01	139	230	18	136	381	12	128	461	07	105	176	27	145	689	28	143	073	04	093	180
16	145	122	05	147	864	30	146	337	18	107	358	02	209	957	03	150	937	15	151	012
20	165	520	12	158	365	05	169	470	22	128	827	26	272	818	04	154	867	16	185	455
04	185	481	28	214	184	21	244	433	23	156	440	22	299	317	19	158	359	07	227	277
09	211	316	14	215	757	23	270	849	15	171	157	18	306	475	29	304	615	02	304	400
14	248	348	13	224	846	25	274	407	08	220	097	20	311	653	06	369	633	30	316	074
25	249	890	15	227	809	10	290	925	20	252	066	15	348	156	18	390	536	18	328	799
13	252	577	11	280	898	01	323	490	04	268	574	16	381	710	17	403	392	20	332	288
30	273	088	01	331	975	24	352	291	14	275	302	01	411	607	23	404	182	26	371	216
18	277	689	10	399	992	15	361	155	11	297	589	13	417	715	01	415	457	19	448	754
22	372	958	30	417	787	29	374	882	01	358	305	21	472	484	07	437	696	13	487	598
10	461	075	08	439	921	08	432	139	09	412	069	04	478	885	24	446	546	12	546	640
28	519	536	20	472	484	04	467	266	16	429	834	25	479	080	26	485	768	24	550	038
17	520	090	24	498	712	22	508	880	10	491	203	11	566	104	15	511	313	03	604	780
03	523	519	04	516	396	27	632	191	28	542	306	10	576	659	10	517	290	22	621	930
26	573	502	03	548	688	16	661	836	12	563	091	29	665	397	30	556	853	21	629	154
19	634	206	23	597	508	19	675	629	02	593	321	19	739	298	25	561	837	11	634	908
24	635	810	21	681	114	14	680	890	30	692	198	14	749	759	09	574	599	05	696	459
21	679	841	02	739	298	28	714	508	19	705	445	08	756	919	13	613	762	23	710	078
27	712	366	29	792	038	06	719	441	24	709	717	07	798	183	11	698	783	29	726	585
05	780	497	22	829	324	09	735	040	13	820	739	23	834	647	14	715	179	17	749	916
23	861	106	17	834	647	17	741	906	05	848	866	06	837	978	16	770	128	04	802	186
12	865	377	16	909	608	11	747	205	27	867	633	03	849	964	08	815	385	14	835	319
29	882	635	06	914	420	20	850	047	03	883	333	24	851	109	05	872	490	08	870	546
08	902	020	27	958	856	02	859	356	17	900	443	05	859	935	21	865	999	28	871	539
04	931	482	26	981	976	07	870	612	21	914	483	17	863	220	02	958	177	25	971	369
02	977	172	07	983	624	03	916	463	29	950	753	09	863	147	27	961	980	27	984	252

Col No 22			Col No 23			Col No 24			Col No 25			Col No 26			Col No 27			Col No 28		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
12	051	032	26	051	187	08	015	521	02	039	005	16	076	102	21	050	952	29	042	039
11	068	980	03	053	256	16	068	994	16	061	599	01	033	886	17	085	403	07	105	293
17	089	309	29	100	159	11	118	400	26	068	054	04	058	686	10	141	624	25	115	420
01	091	371	13	102	465	21	124	565	11	073	812	22	090	602	05	154	157	09	126	612
10	100	709	24	110	316	18	153	158	07	123	649	13	114	614	06	164	841	10	205	144
30	121	744	18	114	300	17	190	159	05	126	658	20	136	576	07	197	013	03	210	054
02	166	056	11	123	208	26	192	676	14	161	189	05	138	228	16	215	363	23	234	533
23	179	529	09	138	182	01	237	030	18	166	040	10	216	565	08	222	520	13	266	799
21	187	051	06	194	115	12	283	077	28	248	171	02	233	610	13	269	477	20	305	603
22	205	543	22	234	480	03	286	318	06	255	117	07	278	357	02	288	012	05	372	223
28	230	648	20	274	107	10	317	734	15	261	928	30	405	273	25	333	633	26	385	111
19	243	001	21	331	292	05	337	844	10	301	811	06	421	807	28	348	710	30	422	315
27	267	990	08	346	085	25	441	336	24	363	025	12	426	583	20	362	961	17	453	783
15	283	440	27	382	979	27	469	786	22	378	792	08	471	708	14	511	989	02	460	916
16	352	049	07	387	865	24	473	237	27	379	959	18	473	738	26	540	903	27	461	841
03	377	648	28	411	776	20	475	761	19	420	557	19	510	207	27	587	643	14	483	095
06	357	769	16	444	999	06	557	001	21	467	943	03	512	329	12	603	745	12	507	375
09	409	428	04	515	993	07	610	238	17	494	225	15	640	329	29	619	895	28	509	748
14	465	456	17	518	827	09	617	041	09	620	081	09	665	354	23	623	333	21	583	804
13	499	651	05	539	620	13	641	648	30	623	106	14	680	884	22	674	076	22	567	993
04	539	972	02	623	271	22	664	291	03	625	777	26	703	622	18	670	904	16	689	339
18	560	747	30	637	374	04	668	856	08	651	790	29	739	394	11	711	255	06	727	298
26	575	892	14	714	364	19	717	232	12	715	599	25	759	386	01	790	392	04	731	814
29	756	712	15	730	107	02	776	504	23	782	093	24	803	602	04	813	611	08	807	983
20	760	920	19	771	552	29	777	548	20	810	371	27	842	491	19	843	732	15	833	757
05	847	925	23	780	662	14	823	223	01	841	726	21	870	435	03	844	511	19	895	464
25	872	891	10	926	888	23	848	264	29	862	009	28	906	367	30	858	299	18	916	384
24	874	135	12	939	204	30	892	817	25	891	873	23	948	367	09	929	199	01	948	610
08	911	215	01	937	714	28	943	190	04	917	264	11	956	142	24	931	263	11	926	799
07	948	545	23	974	398	13	975	962	13	958	990	17	993	989	15	939	947	24	978	633

SAMPLING FROM A STOCKPILE

1. Designate sections or blocks as specified in the sampling procedure being used. Designate X - Y coordinates as described in the sampling procedure.

2. Select a column of random numbers in Table 1 by placing 28 pieces of cardboard 1 inch square, numbered 1 through 28, into a container, shaking them so that they are well mixed and drawing one out.

3. Go to the column of random numbers identified with the number drawn from the container. In subcolumn A, locate all numbers equal to or less than the number of sampling locations in each block or section. The corresponding numbers in subcolumns B and C may be used to locate the X - Y coordinates for one block or section.

4. Multiply the total length of the block or section in the X direction by the decimal values in subcolumn B, found opposite the number located in subcolumn A, to find the length of coordinate X. Multiply the width of the block or section in the Y direction by the corresponding decimal value from subcolumn C, to find the length of coordinate Y.

5. Repeat the procedure for each block or section.

FLORIDA DOT AND WISCONSIN DOT SAMPLING PROCEDURES

The Florida Department of Transportation (FDOT) utilizes the following general sampling procedures for characterizing the existing materials:

1. Review the existing construction records and/or prior sampling records for the proposed project area to identify changes in the existing materials.

2. Review the variation in degree or class of cracking throughout the project area. Identify areas of high cracking which may have asphalt viscosities which may greatly exceed those in other sections of the roadway.

3. Take a minimum of three 6 inch cores per lane mile. Consideration should be given for the factors found in steps one and two in choosing the locations in order to arrive at a representative cross-section of the project. This preliminary information is used for bidding purposes on the project as the Composition of Existing Pavement.

4. If the contractor plans on using milling on the project, he must use the following procedures for obtaining representative samples for his mix design:

A. The contractor must cut 10 six-inch cores in locations which are to be designated by the Bureau of Materials and Research.

B. As an alternative, he may mill the pavement to the full depth shown on the plans for pavement removal for a length of approximately 200 feet. Samples of this milled material are then used for the mix design.

C. Any variations to the above two methods must be requested in writing to the State Materials and Research Engineer.

5. When the contractor is using RAP stockpiled from a previous FDOT project and the Composition of Existing Pavement is known, the contractor can use the existing information on the RAP to design the mix.

6. When the contractor wants to use stockpiled RAP where the composition is not known, he must use the following procedures:

A. The contractor must submit a bag of RAP, made up of material sampled from several locations within the stockpile, to the Bureau of Materials and Research at least four weeks prior to the start of his mix design. The Department will run viscosities on the asphalt recovered from the RAP and provide this information to the contractor.

B. The contractor must run at least six gradation analyses of the RAP. The samples of RAP are to be taken from random locations from the stockpile.

C. The contractor must then request the District Bituminous Engineer to make a visual inspection of the stockpile. Based on the visual inspection, the District Bituminous Engineer will determine the suitability of the stockpile.

D. When the contractor submits his proposed mix design for approval, he must include the results of the extraction gradation analyses required above.

The Wisconsin Department of Transportation (WisDOT) uses the following general procedures for obtaining representative samples of the existing pavement materials:

1. For preliminary testing of the materials prior to preparing the project plans and specifications, WisDOT requires:

A. Samples should represent pavement edges, lane centerline, and wheel paths.

B. Samples must be taken from enough points along the length of the roadway so that a composite sample will be reasonably representative of the total cross-section of the material to be recycled.

C. Sampling can be by eight inch cores or equivalent sized pieces obtained by chisel or sawing.

2. For final mix design, WisDOT requires that the samples be taken from the milled or processed RAP. No specific sampling methods are mentioned for obtaining the samples, however the importance of obtaining representative samples for testing is emphasized.

SAMPLE TESTING

Once representative samples have been obtained, the composition is normally determined through tests for:

A. Aggregate Gradation

B. Asphalt Content

C. Asphalt Viscosity at 60 deg C (140 deg F) and or Asphalt Penetration at 25 deg C (77 deg F)

Aggregate gradation is obtained by running a sieve analysis on the recovered aggregate portion of the RAP. The standard tests are ASTM C 117 and C 136 (AASHTO T 11 and T 27). The final mix design should be based on the properties which the RAP will have at the cold feed stockpile of the plant. The reason for this is that the milling or crushing operations will alter the aggregate gradation by increasing the percentage of fines.

Samples which have been taken through cores in the existing pavement will not have this final aggregate gradation. Some states, including Florida, have developed a table which will provide an estimate for the gradation of the RAP after milling. Table 2 provides these factors for the State of Florida.

TABLE 2 - ADJUSTMENT FACTORS FOR GRADATION AFTER MILLING

(FROM FDOT ASPHALT PLANT TECHNICIAN CERTIFICATION STUDY GUIDE)

Sieve Size	Coarse*	Intermediate**	Fine***
3/4"	1.00	1.00	1.00
1/2"	1.03	1.02	1.00
3/8"	1.06	1.03	1.00
#4	1.16	1.08	1.00
#10	1.24	1.12	1.00
#40	1.27	1.13	1.00
#80	1.49	1.25	1.12
#200	1.84	1.42	1.21

* Coarse Mixes - Type 1, Binder, Type S, FC-2, and ABC-3

** Intermediate Mixes - Type II and III, FC-1 and 4, ABC-2

*** Fine Mixes - SAHM and ABC-1

To evaluate the asphalt content, the standard method used is ASTM Designation D 2172 (AASHTO T 164). The test allows for the quantitative separation of the aggregate and asphalt. The asphalt content is then determined on the basis of the relative weights of the extracted asphalt and aggregate.

The extracted asphalt can be reclaimed from solution by ASTM Method D 1856 (AASHTO T 170). Its viscosity at 60 deg C (140 deg F) can be determined using ASTM D 2171 (AASHTO T 202). Standard penetration tests could also be run if desired.

NEW MATERIALS

New asphalt cement, recycling agents, aggregate and various additives such as anti-stripping agents must be evaluated in preparation for the mix design process.

New asphalt cement which is added to the recycled mix serves two main purposes. It increases the total asphalt content up to the optimum amount for the mix and it blends with the aged asphalt to produce an asphalt blend meeting the desired viscosity. Common asphalt cements used in hot mix recycling are AC-10, AC-5 or AC-2.5 (AR-4000, AR-2000 or AR-1000; 85-100, 120-150 or 200-300 pen.). These asphalt cements should meet the requirements of standard specifications ASTM D 3381 or D 946 (AASHTO M 226 or M 20).

Recycling agents can be used in addition to or in lieu of adding new asphalt cement to the recycled mix. Recycling agents are organic materials with chemical and physical characteristics selected to restore the aged asphalt cement to the desired specifications. The main consideration is to bring the viscosity of the aged asphalt cement within specifications.

Recycling agents are usually effective. The main drawback at this point in time is that there are no nationwide American standard specifications for these materials. A Pacific Coast Conference of Asphalt Users and Producers adopted a set of tentative specifications for recycling agents in 1977. These tentative specifications were submitted to ASTM for consideration in the development of standards for recycling agents. These proposed specifications were published in the 198[illegible] Proceedings of the Association of Asphalt Paving Technologists (Volume 4[illegible]).

The FDOT requires asphalt recycling agents to meet the following minimum standards:

TABLE 3 - ASPHALT RECYCLING AGENT STANDARDS

(FROM FDOT SPECIFICATIONS)

1. Absolute Viscosity ([illegible]) after the Thin Film Oven Test (TFOT)	3:1 ratio max.
2. Smoke Point	2[illegible] deg F min.
3. Flash Point	4[illegible] deg F min.
4. Solubility	9[illegible].5 percent

For emulsified recycling agents, FDOT requires that they be used in mixes with at least 4[illegible] % RAP, and that they meet the following minimum standards:

TABLE 4 - EMULSIFIED RECYCLING AGENT STANDARDS

(FROM FDOT SPECIFICATIONS)

1. Storage Stability, 24 hour	1.[illegible] percent max.
2. Sieve Test	[illegible] percent max.
3. Residue by Distillation	6[illegible] percent min.
4. Residue shall meet the requirements of Table 3	

The [illegible] Materials and Research [illegible] approv[illegible] [illegible]

New aggregate can be any aggregate which is normally used for hot-mix asphalt concrete. It should be kept in mind that it must be blended with the reclaimed aggregate to meet the required specification though. It should also be kept in mind as to whether the recycled mix is to be used as a base or surface course.

Additives such as anti-stripping agents must be looked at as well. Stripping depends mainly on the aggregates. If the reclaimed aggregate showed a problem of stripping, then the recycled mix would show the same tendency. Anti-stripping agent would then be required. The blend of aggregates should be checked for resistance to stripping. The immersion compression test, "Effect of Water on Cohesion of Compacted Bituminous Mixtures," ASTM Designation D 1075 (AASHTO T 165) can be used. The retained strength should exceed 75 percent of the original strength.

CONCLUSION

The proper characterization of the existing materials is extremely important to the entire hot-mix recycling process. The sampling plan chosen for the project is critical. The results of the tests on the various samples will show the direction in which the mix design will have to go.

The sampling plans and techniques outlined in this chapter can be adapted for any project. Engineering judgement as to how much sampling is enough will come into play. Inadequate sampling can lead to inadequate mix design and costly future change orders. Too much sampling can be very expensive and time consuming.

The variability of the samples may lead to the conclusion that more than one mix design will have to be used, or that significant mixing of the RAP will be needed to obtain a more uniform product. On the other hand, the variability may be small enough that it will not significantly affect the mix design. An analysis of the variances found will be required in order to make these determinations.

With the existing and new materials properly characterized, the hot-mix recycling mix design process is ready to proceed.

CHAPTER FOUR

HOT-MIX RECYCLING DESIGN

INTRODUCTION

This chapter presents the hot-mix recycling design procedure as advocated by The Asphalt Institute. This mix design procedure uses either the Marshall or the Hveem method. The following steps summarize this procedure:

1. Determine the aggregate gradation, asphalt content, and viscosity of extracted asphalt from the RAP.

2. Determine the gradation of the reclaimed aggregate material and/or new aggregate.

3. Calculate the combined aggregate gradation in the recycled mix.

4. Approximate the asphalt demand of the combined aggregates.

5. Estimate the percent new asphalt and/or recycling agent in the mix.

6. Select grade of new asphalt and/or recycling agent.

7. Conduct trial mix designs by the Marshall or Hveem methods.

8. Select a job mix formula.

This chapter also presents an outline of how both the Florida Department of Transportation (FDOT) and the Wisconsin Department of Transportation (WisDOT) are currently conducting asphalt hot-mix recycling design. These states currently use asphalt hot-mix recycling to a large degree.

THE ASPHALT INSTITUTE HOT-MIX RECYCLING DESIGN

In starting the mix design, the existing and new material properties found from the methods discussed in Chapter Three, should be known. Additionally, the specification required for the recycled mix should be established. This means that at least the aggregate gradation, asphalt cement viscosity range, minimum stability, and percent air voids (normally a 4 percent minimum), should be established.

A trial percentage of RAP in the mix should be established. This amount should be the highest percentage that would be considered to be practical. The type of plant which will be used on the job will often govern the maximum amount of RAP. In general, batch plants can handle up to 50 percent (without some type of auxiliary method of preheating the RAP), with 10 to 35 percent being the most practical range. In general, drum-mix plants can handle up to 70 percent, with the most practical range being 10 to 50 percent. The amount and viscosity of the aged asphalt may also become a limiting factor on the total percent RAP in the mix.

Steps 1 and 2 - These steps (as listed in the introduction to this Chapter) will have already been completed at this point.

Step 3 - The combined gradation of the aggregate in the RAP and the new aggregate must be calculated. This gradation must meet the specifications established for the project. After the blend of aggregate has been established, the total amount of new aggregate is expressed as r, in percent of the total aggregate in the mix (expressed as a whole number, i.e. 50% = 50).

Step 4 - The approximate asphalt demand of the combined aggregates must be calculated next. This can be done by either using the Centrifuge Kerosene Equivalent (CKE) test or using the following empirical formula:

$$P = 0.035a + 0.045b + Kc + F$$

where:

P = approximate total asphalt demand of recycled mix, percent by weight of mix

a = percent (expressed as a whole number) of mineral aggregate retained on the No. 8 sieve

b = percent (expressed as a whole number) of mineral aggregate passing the No. 8 sieve and retained on the No. 200 sieve

c = percent (expresses as a whole number) of mineral aggregate passing the No. 200 sieve

K = 0.15 for 11-15 perc. passing the No. 200 sieve

0.18 for 6-10 perc. passing the No. 200 sieve

0.20 for 5 perc. or less passing the No. 200 sieve

F = 0 to 2.0 percent. Based on absorption of light or heavy aggregate. In the absence of other data, a value of 0.7 is suggested.[8]

With the approximate total asphalt demand calculated, a basis for a series of trial mixes is established. Trial mixes normally vary the asphalt content in 0.5 percent increments on either side of the approximate total asphalt demand.

Step 5 - An estimate for the quantity of new asphalt and/or recycling agent to be added to the trial mixes of the recycled mixture can now be made. This quantity is expressed as percent by weight of total mix and is calculated by the following formula:

$$P_{nb} = \frac{(100^2 - rP_{sb})\ P_b}{100\ (100 - P_{sb})} - \frac{(100 - r)\ P_{sb}}{100 - P_{sb}}$$

where:

P_{nb} = percent* of new asphalt in recycled mix

r = percent* new aggregate as calculated in step 3 above

[8]The Asphalt Institute, Asphalt Hot-Mix Recycling (MS-20), 2nd ed., (The Asphalt Institute, College Park, Md., 1986), p. 12.

P_b = percent*, asphalt content of reclaimed asphalt pavement asphalt demand, determined by CKE or empirical formula in step 4 above

P_{sb} = percent*, asphalt content of reclaimed asphalt pavement

* - expressed as a whole number

Step 6 - The selection of the grade of the new asphalt or recycling agent is next. First the percent of the new asphalt, P_{nb}, to the total asphalt content, P_b, is calculated by the following formula:

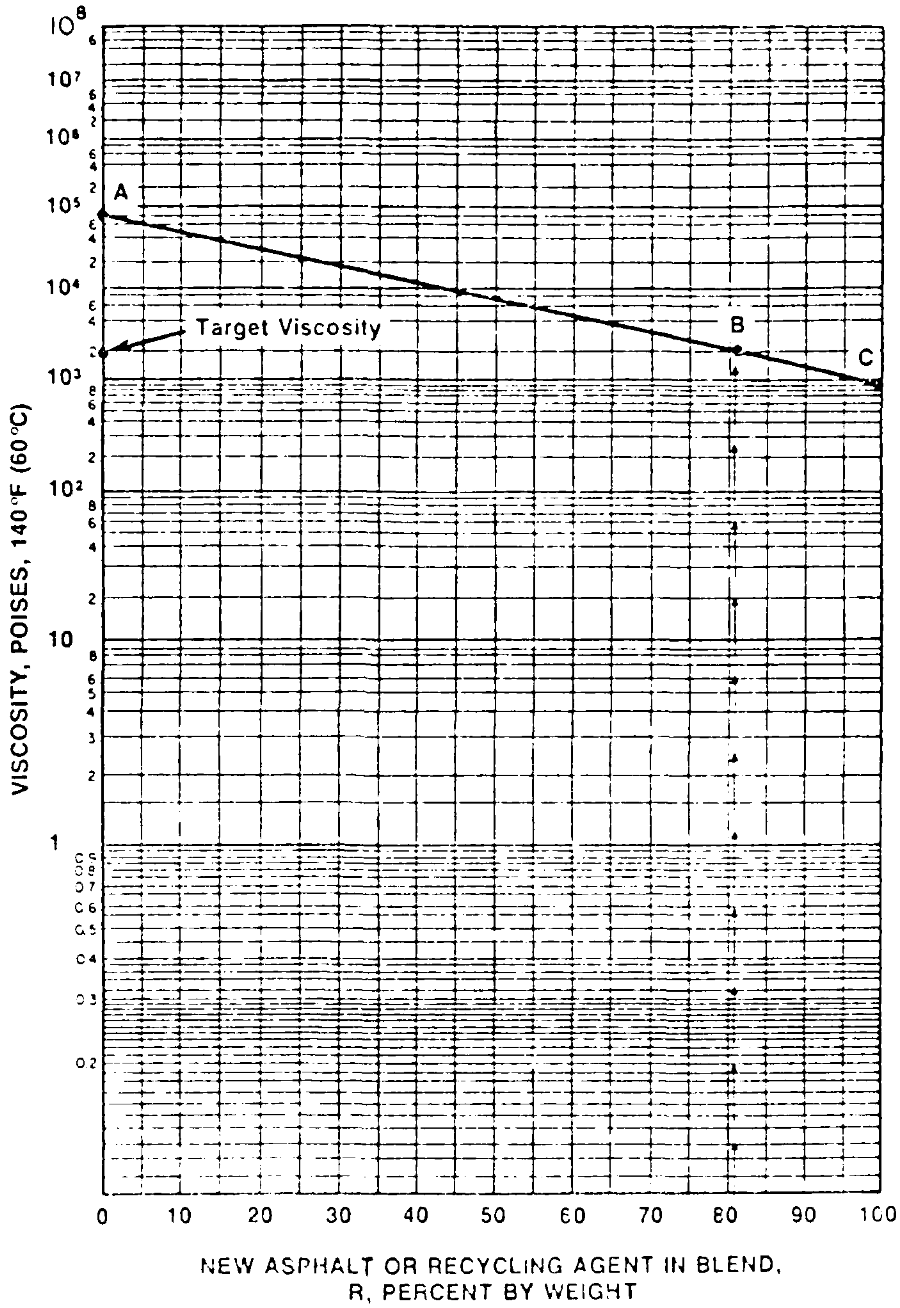
$$R = \frac{100\ P_{nb}}{P_b}$$

The grade of new asphalt and/or recycling agent is determined using a log-log viscosity versus percent new asphalt blending chart. An example of this chart is shown in Figure 1.

To use the chart, plot the viscosity of the aged asphalt in the RAP on the left hand vertical scale (point A). Draw a vertical line representing the percentage of new asphalt, R, calculated above and determine its intersection with the horizontal line representing the target viscosity (point B). The target viscosity is usually the viscosity of the mid-range of the grade of asphalt normally used in new mixes for the project location. Then draw a straight line from point A, through point B and extend it to intersect the right hand scale, point C.

FIGURE 1 - EXAMPLE ASPHALT VISCOSITY BLENDING CHART

(FROM THE ASPHALT INSTITUTE MS-20)



Point C then represents the viscosity at 60 deg C (140 deg F) of the new asphalt and/or recycling agent required to blend with the asphalt in the RAP to obtain the target viscosity in the blend. The grade of asphalt and/or recycling agent which has a viscosity range that includes or is closest to the viscosity at point C will then be selected.

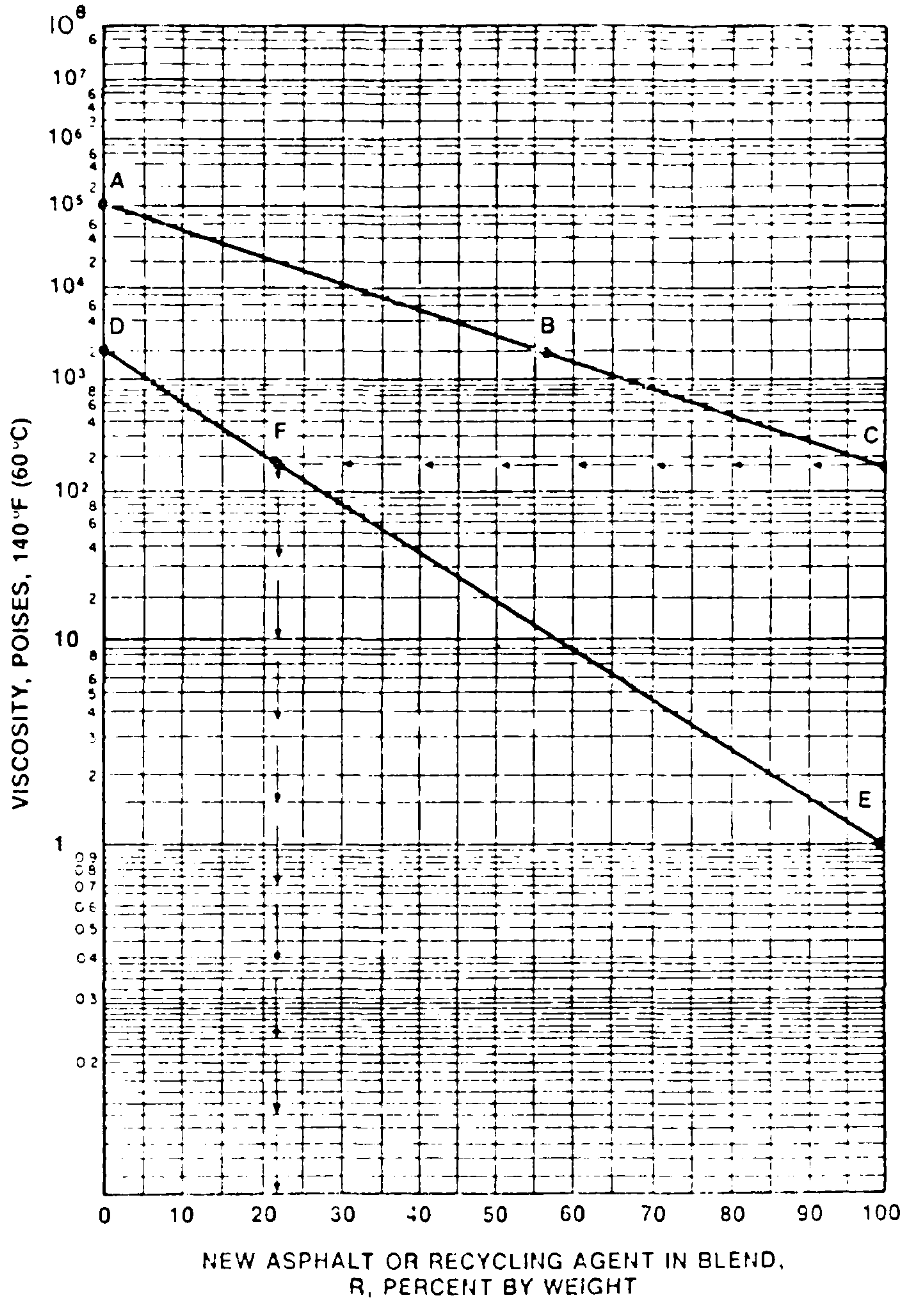
Sometimes the engineer may wish to use a certain grade of asphalt cement in the mix design and then add recycling agent to the mix to give the desired target viscosity. Figure 2 shows an example of how this is done on the same blending chart as just described.

In the example shown on Figure 2, point A represents the viscosity of the aged asphalt (100,000 poises). Point B is then found using a target viscosity of 2,000 poises and a value of R equal to 57 (the equation to calculate R was shown earlier in this step). The line projected through points A and B, locate point C (180 poises).

The engineer has decided to use an AC-20 and a recycling agent with a viscosity of 1 poise in the recycled mix design. To calculate the blend of these two components to give the required viscosity of 180 poises (and ultimately blend with the aged asphalt to meet the target viscosity of 2000 poises), point D is then plotted on the left hand vertical scale at 2,000 poises (target viscosity). Point E is then plotted on the right hand vertical scale at 1 poise (viscosity of the recycling agent to be used). Point F is

FIGURE 2 - EXAMPLE ASPHALT VISCOSITY BLENDING CHART

(FROM THE ASPHALT INSTITUTE MS-20)



located by finding the point on line D - E which has a viscosity of 180 poises. Projecting point F down to the horizontal scale shows a value of R equal to 22 percent.

This result indicates that a tank of AC-20 which contains 22 percent of the recycling agent should have a viscosity of 180 poises. This combination will then blend with the aged asphalt to meet the target viscosity of 2,000 poises.

The Asphalt Institute does suggest that when selecting a grade of asphalt cement for recycling, that the following guide be used:[9]

Up to 20% RAP - No change in asphalt grade.

21% RAP or more - Do not change more than one grade (i.e. from AC-20 to AC-10).

Step 7 - Trial mix designs are then made using either the Marshall or Hveem apparatus. Table 5 provides the formulas needed to proportion the materials for asphalt contents by both weight of total mix and by weight of aggregate.

---

[9]The Asphalt Institute, Asphalt Hot-Mix Recycling (MS-20), 2nd ed. (The Asphalt Institute, College Park, Md., 1986), p. 16.

TABLE 5

FORMULAS FOR PROPORTIONING MATERIALS FOR RECYCLED HOT MIXTURES

(Where blend of aggregates in the mix is kept constant)

(FROM THE ASPHALT INSTITUTE MS-20)

	For Asphalt Content	
	by wt. of total mix	by wt. of aggregate
% New Asphalt, P_{nb}	$\frac{(100^2 - r\,P_{sb})P_b}{100\,(100 - P_{sb})} - \frac{(100 - r)P_{sb}}{100 - P_{sb}}$	$P_b - \frac{(100 - r)P_{sb}}{100}$
% RAP, P_{sm}	$\frac{100\,(100 - r)}{100 - P_{sb}} - \frac{(100 - r)P_b}{100 - P_{sb}}$	$\frac{(100 + P_{sb})(100 - r)}{100}$
% New Agg. and/or RAM, P_{ns}	$r - \frac{rP_b}{100}$	r
Total	100	$100 + P_b$
% New Asphalt to Total Asphalt Content, R	$\frac{100\,P_{nb}}{P_b}$	$\frac{100\,P_{nb}}{P_b}$

Where:

P_{sm} = Percent salvage mix (RAP) in the recycled mix

P_b = Asphalt content of recycled mix, %

P_{sb} = Asphalt content of salvaged mix (RAP), %

P_{nb} = Additional asphalt and/or recycling agent in recycled mix, %

P_{ns} = Percent additional aggregate (new or reclaimed aggregate material)

r = Percent new and/or reclaimed aggregate material to total aggregate in recycled mix

R = Percent new asphalt and/or recycling agent to total asphalt in recycled mix

Note: All percentages should be expressed as whole numbers.

Test specimens should be made with asphalt contents at the approximate asphalt demand, with three asphalt contents below and one above the approximate asphalt demand when the Marshall test apparatus is used. When the Hveem test apparatus is used, test specimens should have asphalt contents at the approximate asphalt demand, with two asphalt contents below and one above the approximate asphalt demand. The test specimen asphalt contents should be in 0.5 percent increments.

The test specimens should be made by ASTM Method D 1559 when the Marshall test apparatus is used and by ASTM Method D 1561 when Hveem test apparatus is used, with the following changes or special provisions:[4]

1. If necessary, reduce the RAP in size to pass the one inch sieve and separate it by dry sieving into the following size fractions:

   A. 1 to 3/4 inch

   B. 3/4 to 3/8 inch

   C. 3/8 to No. 4

   D. Passing the No. 4

2. Heat the new aggregate 50 deg F above the standard ASTM Method D 1559 or ASTM Method D 1561 mixing temperatures.

3. Heat the RAP to the standard ASTM Method D 1559 or ASTM Method D 1561 compaction temperatures.

---

[4]Bernard F. Kallas, Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete (RR-84-2). (The Asphalt Institute, College Park, Md.,1984), pp. E-19-20.

4. Dry mix the new aggregate and reclaimed asphalt concrete 30 seconds.

5. Add the new asphalt and/or recycling agent previously heated to the mixing temperature to the new aggregate and RAP and mix for 60 seconds.

6. Transfer the completed batches of mix to covered tins and place them in an oven maintained at the compaction temperature for a minimum of one hour and not exceeding two hours prior to compaction of the specimens.

7. Prepare duplicate batches of mix at each asphalt content for determining the theoretical maximum specific gravity of bituminous paving mixtures by ASTM Method D 2041.

Note: The mixing and compaction temperatures are based on the viscosity of the blend established by the aged asphalt cement from the RAP and the new asphalt cement and/or recycling agent.

In running the tests, first determine the bulk specific gravity of the compacted specimens according to ASTM Method D 2726. Then determine the maximum load and flow value of the specimens according to ASTM Method D 1559 if Marshall test apparatus are used, or the stabilometer value of the specimens according to ASTM Method D 1561 if the Hveem apparatus are used. Calculate the percent air voids in the compacted specimens according to ASTM Method D 3203.

For the Marshall test, graphs of maximum load (stability), density, flow value and percent air voids versus recycling agent or new asphalt content, should be made. For the Hveem test, graphs of stabilometer values, density and percent air voids versus recycling agent or new asphalt, should be made.

In selecting the optimum recycling agent or new asphalt content in the Marshall test, determine the recycling agent or asphalt contents from the above graphs which give the following:

A. Maximum load (stability)

B. Maximum density

C. Four percent air voids

The optimum recycling or asphalt content will be the average of the above three values. If peaks are not reached for the maximum stability or density curves, select the optimum as the recycling agent or new asphalt content giving four percent air voids.

For the Hveem test, the following steps are used to select the optimum recycling agent or new asphalt content:

1. Using Figure 3, insert in Step 1 of the pyramid, the asphalt contents used for preparing the series of mix design specimens. Insert the asphalt contents in increasing amounts from left to right.

2. Select from Step 1 the three highest asphalt contents that do not exhibit moderate or heavy surface flushing and record them on Step 2. Surface flushing is considered "slight" if the surface has a slight sheen. It

would be considered "moderate" if sufficient free asphalt is apparent to cause paper to stick to the surface but no distortion is noted. Surface flushing would be considered "heavy" if there is sufficient free asphalt to cause surface puddling or specimen distortion after compaction.

3. Select from Step 2 the two highest asphalt contents that provide the specified minimum stabilometer value and enter them in Step 3.

4. Select from Step 3 the highest asphalt content that has at least 4.0% air voids and enter it in Step 4.

5. The asphalt content in Step 4 is the optimum asphalt content. Although, if the maximum asphalt content used in the design specimens is the optimum, there is a problem. In this case the optimum is not valid and additional specimens with increased asphalt contents in 0.5 percent increments must be made. The new optimum asphalt content can then be determined with this additional data.

FIGURE 3

HVEEM OPTIMUM ASPHALT CONTENT PYRAMID

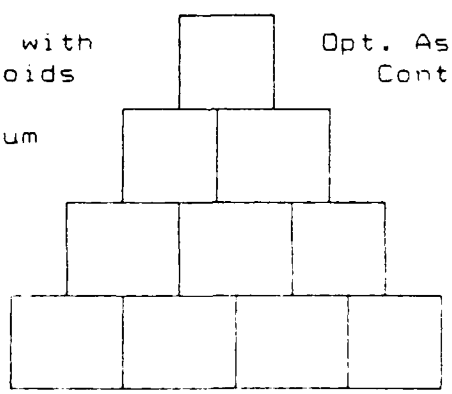
Step 4 - Maximum asphalt content with 4 or more percent air voids

Opt. Asphalt Content

Step 3 - Specimens meeting minimum stability requirement

Step 2 - Specimens with no flushing

Step 1 - Design series



Step 8 - The results of both test methods then need to be compared against the project specifications. These should be the same specifications as used for mixes with all new materials. If all criteria are met, then this becomes the job-mix formula. If not, then adjustments need to be made to the recycled mix and the mix design process started again from the appropriate step.

THE FDOT HOT-MIX RECYCLING DESIGN

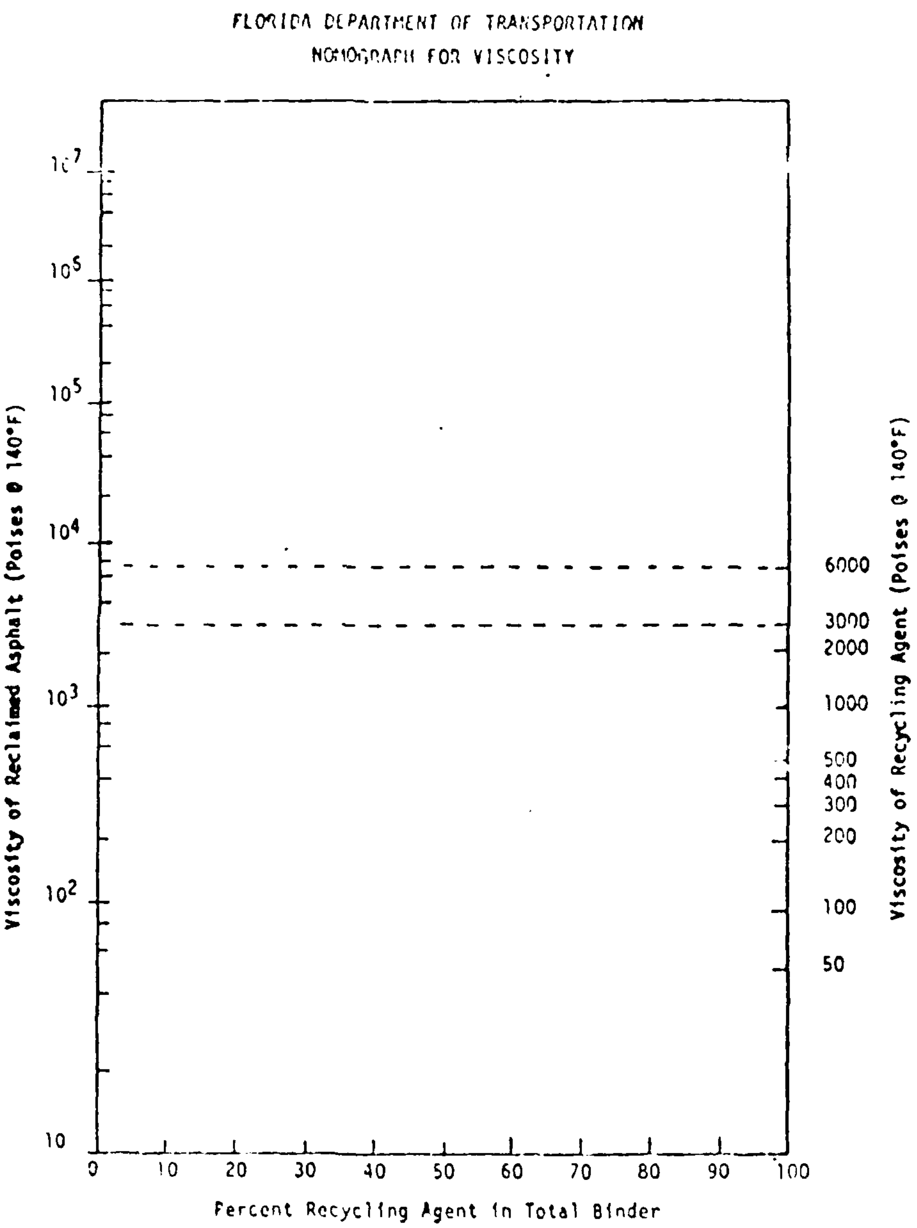
Chapter 2 discussed how FDOT characterized the existing pavement materials and how the contractor obtained samples for his mix design. In Florida, the contractor is responsible for providing the final design of the recycled mix. The proposed job-mix formula and samples of all material components are then sent to the Bureau of Materials and Research. A copy of the job-mix formula is sent to the District Bituminous Engineer at the same time.

The FDOT places a maximum limit of 60% RAP on the hot-mix recycling design. The contractor must then choose what percent RAP he will use in his job-mix formula based on his equipment capabilities and the materials available. The contractor will normally try to maximize the amount of RAP used in his job-mix formula. This has normally come out to an average of about 50% RAP in Florida.

Figure 4 shows the nomograph used by FDOT to select the grade of recycling agent to be used. The viscosity of the

FIGURE 4 - FDOT NOMOGRAPH FOR VISCOSITY

(FROM FDOT ASPHALT PLANT TECHNICIAN CERTIFICATION STUDY GUIDE)



aged asphalt is provided to the contractor from the samples discussed in Chapter 2. The target viscosity used by FDOT was 4500 ± 1500 poises (this range is indicated by the dashed lines on Figure 4), but has now been revised to 6000 ± 2000 poises. This is the same type of blending chart as discussed in The Asphalt Institute design section and has the same procedures for using it.

The following procedures are used in handling the RAP material and in preparing the combined aggregate batches for the recycled mix design:

1. Place the ten 6 inch roadway cores (the portions which represent the thickness to be milled) in an oven at 230 deg F, until they can be broken down into small pieces without degrading the aggregate in the mix.

2. Spread the broken down RAP material in a thin layer in a flat pan to prevent rebinding and cool to room temperature.

3. Separate the RAP material using a nest of the following sieves: 3/4", 1/2", 3/8", No. 4, No. 10 and pan. Determine the gradation of the material.

4. Combine the RAP material with the new aggregate components to form the individual batches for preparation of the 2.5" height by 4.0" diameter Marshall specimens.

The RAP material is combined with the new aggregate on the basis of the gradation determined in step 3, rather than the extracted gradation. This is done to correct the difference between the actual gradation of the aggregate in the roadway cores and the gradation which will exist after milling. Approximately 25 percent of the minus #10 material will remain bonded to the coarse aggregate during the gradation of tne RAP material in step 3, which is approximately the same amount that will be generated by the milling operation.

The amount of asphalt contained in the RAP material must be taken into account during the preparation of the combined aggregate batches. If this is not done, the percentage of aggregate from the RAP material will be less than what was wanted.

5. Run the standard Marshall design procedure.

The FDOT specifications have been combined to include both recycled and new mixes. Therefore, they both have the same criteria for selection of the optimum asphalt content based on percent air voids, stability and density. The minimum criteria for the mixes are contained in the FDOT specifications.

The FDOT also requires that the viscosity of the asphalt in the recycled mix be tested on a random basis at a minimum frequency of one sample per 2000 tons of mix. This may be viewed as more of a quality control measure rather than part of the design, but FDOT considers the fact that they have this end-result viscosity specification, to be a significant factor in the design and control of hot-mix recycling. This will also alert the State of any processing deficiencies such as damage by overheating.

The last item of interest in the FDOT method of recycled mix design is the fact that they give the contractor an assumed optimum asphalt content for bidding purposes. This assumed optimum asphalt content for coarse graded mixes is 6.0 percent and for fine graded mixes it is 6.5 percent. This allows for consistent bidding results since the actual optimum asphalt content is not known at that time. When the actual optimum asphalt content has been determined for the job-mix formula and it varies from the assumed optimum, the payment for the mix will be adjusted up or down, based on the cost of the asphalt cement plus 10 percent.

THE WisDOT HOT-MIX RECYCLING DESIGN

The WisDOT first characterizes the pavement materials as discussed in Chapter 2. They then proceed on with a preliminary design which will allow for the project plans and specifications to be drawn up. The final design is not done until the existing pavement materials have been milled or processed. The WisDOT maintains the responsibility for providing both the preliminary and final mix designs.

The WisDOT uses penetration graded asphalt cement in both their new and recycled mixes. Therefore, a target penetration instead of a target viscosity is used in selecting the grade of new asphalt cement to add to the recycled mix. The target penetration is then based on the anticipated average daily traffic. Figure 5 shows how a target penetration is chosen.

Once a target penetration has been chosen, the blend proportions for the aged asphalt and the new asphalt must be determined. Figure 6 shows an example of how this blend is determined. This blending chart is really the same as that used in The Asphalt Institute design except that the vertical scale represents penetration instead of viscosity. This results in lines which slope in the opposite direction to the previous blending chart figures. However, the procedures for using it are the same.

The proportion of the RAP material is then calculated in the following equation:

$$\%S = \left(1 - \frac{ABR}{100}\right)\left(\frac{\%A_t}{\%A_{10\%}}\right)(100)$$

Where:

$\%S$ = percent RAP in the recycled mix

ABR = asphalt blend ratio (as calculated from Figure 6)

$\%A_t$ = total percent asphalt in the recycled mix

$\%A_{10\%}$ = percent salvaged asphalt

FIGURE 5 - WisDOT TARGET PENETRATION CHART

(FROM ZUEHLKE, 1981)

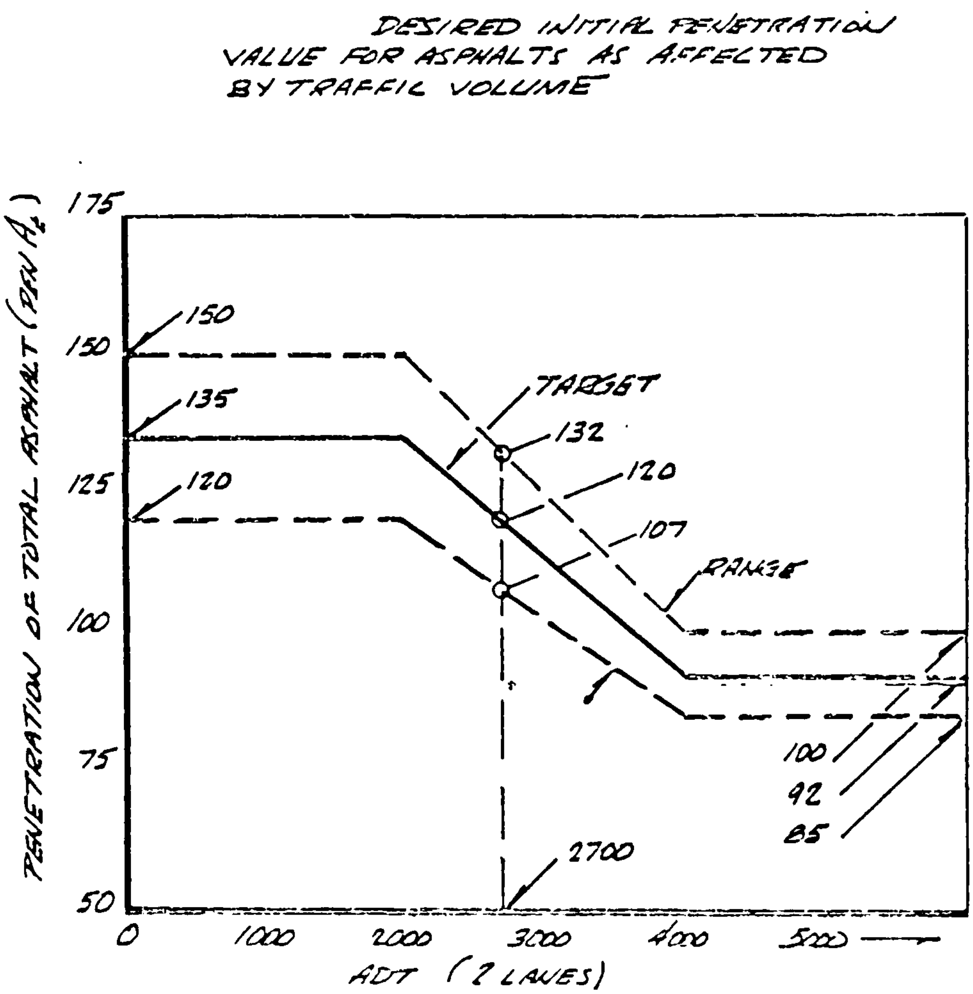
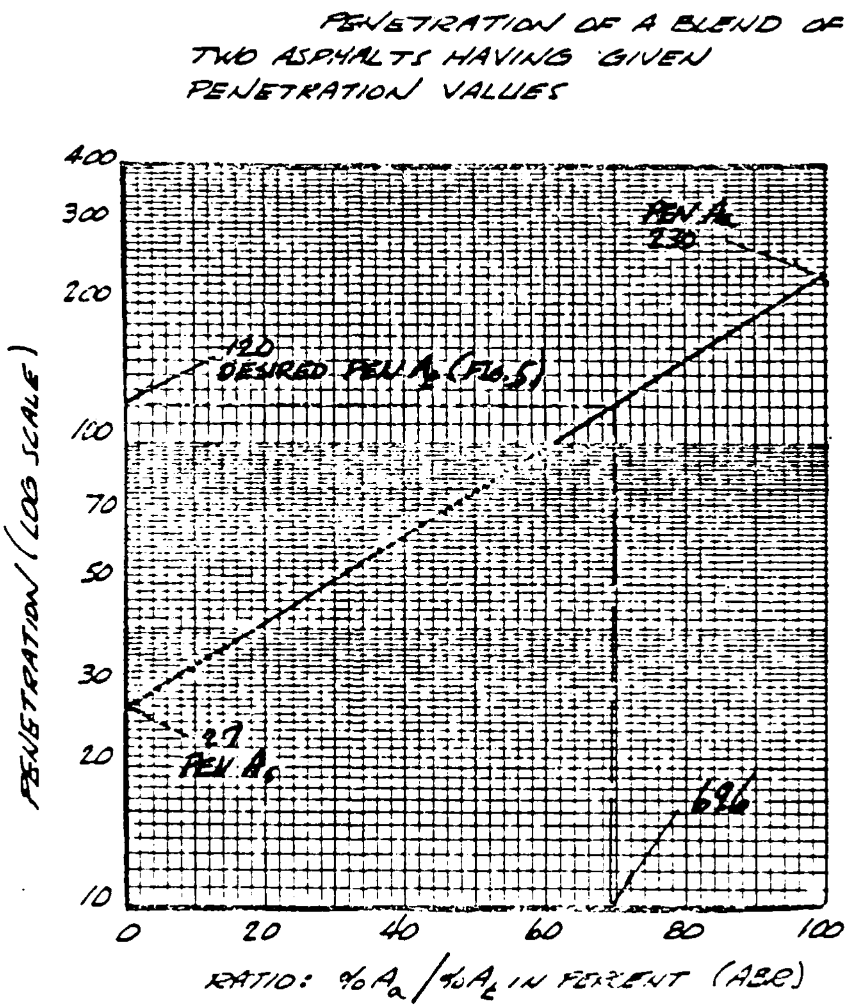


FIGURE 6 - WisDOT ASPHALT PENETRATION BLENDING CHART

(FROM ZUEHLKE, 1981)



Figures 7 and 8 illustrate an example of this general design method as given in the WisDOT guidelines on designing recycled mixes.[8] Figure 7 shows the preliminary design data, while Figure 8 is for the final design.

In looking at Figure 7, Field 1 shows:

1. An <u>estimate</u> of the likely optimum total asphalt content of the new recycled mixture, ($\%A_t$).

2. The measured percent of asphalt in the RAP to be salvaged, ($\%A_{sw}$).

3. The measured penetration of the salvaged asphalt, (Pen A_{sw}).

4. The estimated average ADT data.

5. The required penetration value for the total asphalt content of the recycled mixture, (Pen A_t), as determined from Figure 6. Values are shown for the optimum level and for the allowable range of such values.

Since the optimum grade of the new virgin asphalt, A_n, is not yet known, the computations shown in Field 2 are made to establish the necessary proportions of the RAP material, %S, for the recycled mixture which will satisfy the ABR requirements for a range of penetration values for the added asphalt, (Pen A_a). These data are then plotted in Field 3.

An inspection of these plotted data points indicate that a 120/150 grade of added asphalt, having an actual

---

[8]G.H. Zuehlke, <u>Recycled Bituminous Pavements, Design of Mixture Proportions</u> (Department of Transportation, State of Wisconsin, October, 1981), pp. 11-16.

FIGURE 7 - WisDOT EXAMPLE PRELIMINARY MIXTURE DESIGN

(FROM ZUEHLKE, 1981)

RECYCLED BITUMINOUS PAVING MIXTURES DESIGN OF MIXTURE PROPORTIONS PART 1 - DETERMINE REQUIRED GRADE OF ADDED ASPHALT AND AN ESTIMATE OF PROPORTION OF SALVAGED MATERIAL	"EXAMPLE" 1 "AVERAGE CASE" P.1 of 2

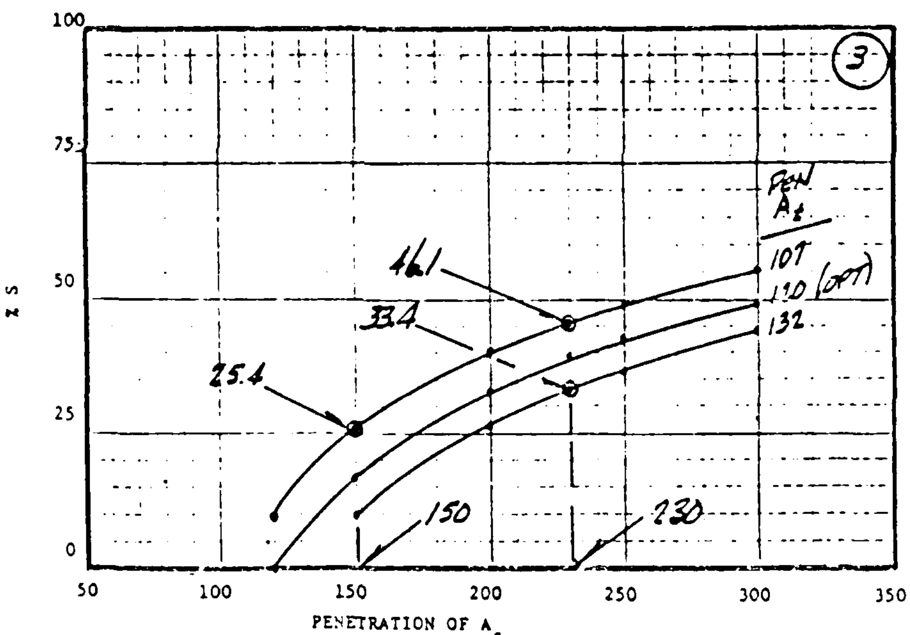
(1)

ESTIM. % A_t	5.80		
% A_s	4.50 ✓	By Test	
PEN A_s	27 ✓	By Test	
LOG PEN A_s	1.431 ✓		
ADT	2700 ✓		
DES. PEN A_t: (From Fig. 1)			
Lo	107 ✓	LOG	2.029
OPT	120 ✓	LOG	2.079
Hi	132 ✓	LOG	2.121

(2)

PEN A_a	LOG PEN A_a	% S AT PEN A_t 107	120	132
85	1.929			
100	2.000			
120	2.079	9.9	0	
150	2.176	25.4	16.8	9.5
200	2.301	40.3	32.9	26.7
250	2.398	49.2	42.5	36.9
300	2.477	55.2	49.0	43.9
230	2.362	46.1	39.2	33.4

$$\% S = \left[1 - \frac{ABR}{100}\right]\left[\frac{\%A_t}{\%A_s}\right]\left[100\right] \qquad ABR = \left[\frac{\text{LOG PEN } A_t - \text{LOG PEN } A_s}{\text{LOG PEN } A_a - \text{LOG PEN } A_s}\right]\left[100\right]$$



REMARKS Use 200/300 AC
Range %S = 33 to 46
at %S = 33, % A_a = 4.3) Prel. Estimate
at %S = 46 % A_a = 3.7) Formula 2

penetration of 150, would allow a proportion of RAP, %S, of a maximum of about 25. This may be too low to be practical. So the use of the 200/300 grade can be considered. Assuming that the actual penetration of the asphalt currently being provided under this grade is about 230, it is shown that the allowed range of proportions of the RAP is from about 33 to about 46.

Assume that the pavement designer had determined that he wanted his percent RAP to be a minimum of about 50 but will attempt to be satisfied with 46 percent. He will then reconsider his total recycled pavement design concepts and prepare the necessary plans, specifications and estimates. In this case he would likely specify the use of 200/300 grade of asphalt and that the percent of RAP will be, as determined by the engineer, within the range of say 46 ± 5.

The above description relates to the derivation of the necessary <u>preliminary</u> mixture design parameters. Later, when the RAP has been removed and processed, a representative sample of this material and of the proposed virgin aggregate and new virgin asphalt are submitted to the laboratory for <u>final mixture design</u> testing. At this time the pavement designer will also inform the laboratory of the desired mixture proportions to be used. In this subject case he would likely suggest using 46 percent RAP in the mixture design process.

In looking at Figure 8, the <u>final</u> mixture design process for WisDOT is illustrated. In Field 4 it is shown that the actual penetration of the proposed new asphalt, (Pen A_n), is 230 as earlier anticipated. The percent asphalt in the RAP is now 4.40 as compared to the 4.50 value determined for the preliminary samples. The penetration of the recovered asphalt is now 30 as compared to the value of 27 obtained for the preliminary samples.

Marshall mix design samples are now prepared and tested having a percent RAP of 46.1 and range of added asphalt contents selected to bridge the likely optimum asphalt content. The derived Marshall test data indicate that the optimum added asphalt content is 3.80 percent and that the total asphalt content, derived as shown in Field 5, is 5.83 percent.

Computations as shown in Field 6, are made for the proportions of RAP and the added new asphalt which will satisfy the shown ABR values and other design criteria. Note that computations are also included for asphalt contents of minus 0.5 percent and plus 0.5 percent from the optimum total asphalt content. This is to provide some latitude in controlling mixture proportions in the field to achieve optimum mixture characteristics. This range of asphalt contents may be limited by other Marshall design criteria.

The computed data are illustrated in Field 7. It is noted that at the reported optimum asphalt content, the

FIGURE 8 - WisDOT EXAMPLE FINAL MIXTURE DESIGN

(FROM ZUEHLKE, 1981)

RECYCLED BITUMINOUS PAVING MIXTURES
DESIGN OF MIXTURE PROPORTIONS
PART 2 - FINAL MIXTURE DESIGN

EXAMPLE 1
"AVERAGE" CASE
P. 2 of 2

4

PEN A_a [130] By Test

LOG PEN A_a [2.362]

$\%A_s$ [4.46] By Test

PEN A_s [30] LOG [1.477]

ESTIM. $\%A_t$ [5.80]

ADT [2700]

DES. PEN A_t = (From FIG. 1)

LO [107] LOG [2.029]

OPT [120] LOG [2.079]

HI [132] LOG [2.121]

5

MARSHALL DATA AT %S = [46.1]

OPT. $\%A_a$ = [3.80]

OPT. $\%A_t$ = OPT. $\%A_a$ + $\left[\%A_s\right]\left[\frac{\%S}{100}\right]$

= [3.80] + [4.46] × [0.461]

= [5.83]

6

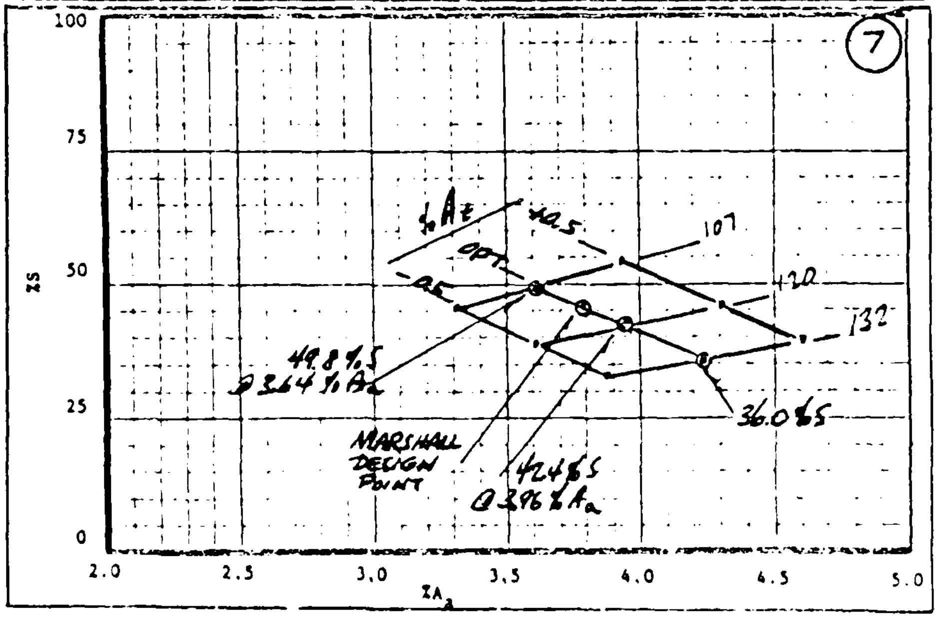
DES. PEN A_t	$\%A_t$		ABR	%S	$\%A_a$
107	-0.5	5.33	61.4	45.5	3.33
	OPT	5.83		49.8	3.64
	+0.5	6.33		54.1	3.95
120	-0.5	5.33	68.0	38.8	3.62
	OPT	5.83		42.4	3.96
	+0.5	6.33		46.0	4.31
132	-0.5	5.33	72.8	32.9	3.88
	OPT	5.83		36.0	4.25
	+0.5	6.33		39.1	4.61

$$\%S = \left[1 - \frac{ABR}{100}\right]\left[\frac{\%A_t}{\%A_s}\right]\left[100\right]$$

$$ABR = \left[\frac{\text{LOG PEN } A_t - \text{LOG PEN } A_s}{\text{LOG PEN } A_a - \text{LOG PEN } A_s}\right]\left[100\right]$$

$$\%A_a = \%A_t - \left[\%A_s\right]\left[\frac{\%S}{100}\right] \text{ OR } = \left[\frac{ABR}{100}\right]\%A_t$$

7



allowable range of RAP is now from 36 to 50 percent, somewhat higher than indicated by the preliminary data. This is the result of the noted change in the percent salvaged asphalt and in the penetration of this salvaged asphalt.

From the results of this data and the decisions made in the process, the engineer would likely specify that the produced recycled mixture have the following composition:

50.0 %	RAP
3.6 %	Added asphalt
46.4 %	Virgin aggregate
100.0 %	Total

As may be necessary, some adjustments may be made subsequently to accommodate specific needs as long as all resulting proportions fall within the illustrated parallelogram.

The WisDOT clearly prefers the use of soft graded asphalt cements over recycling agents. In 1980 they stated based on the best information available to them at the time, that the long term benefit of recycling agents is in some doubt. Therefore, they were going to stay away from them as much as possible.[9] This basic viewpoint was again

[9]G.H. Zuehlke, Recycled Bituminous Pavements (Department of Transportation, State of Wisconsin, February 22, 1980), p. 12.

re-emphasized in 1981 by warning their engineers that recycling agents had not yet proven to be totally effective.[8]

The last item which should be noted in the WisDOT hot-mix recycling design procedure, is that the final mix design is not done until all of the existing material has been processed. Using processed RAP for the final mix design will give the most accurate results. The WisDOT recognizes that their method of waiting for all of the RAP to be processed and then doing the final mix design, could lead to a long period where the roadway would be out of service and the construction held up. The general guidance they have given their field personnel concerning proceeding with the project on the basis of the preliminary design rather than waiting for the final mix design is as follows:

> If the old pavement to be recycled is quite uniform in composition, if the processing is known to not likely degrade the aggregate too badly, if traffic volume is relatively low, if only lower binder courses are involved, if no stability problems are expected and if an acceptable alternative means exists for assuring adequate control at the work, it would be acceptable to produce the paving mixtures before the final mixture design data are available.[9]

---

[8]G.H. Zuehlke, Recycled Bituminous Pavements, Design of Mixture Proportions (Department of Transportation, State of Wisconsin, October, 1981), p. 20.

[9]G.H. Zuehlke, Recycled Bituminous Pavements, Design of Mixture Proportions (Department of Transportation, State of Wisconsin, October, 1981), p. 22.

CONCLUSION

This Chapter has shown how hot-mix recycling design is approached by The Asphalt Institute, FDOT and WisDOT. The Asphalt Institute procedures have been presented in more detail than the general outlined procedures of the two States. It can be seen that while there are many similarities between the procedures of each organization, there are differences as well.

The basic design approach can be looked at as three basic steps:

1. Characterize the materials to be used.
2. Perform a preliminary mix design.
3. Perform a final mix design.

Due to the variable nature of the existing pavement materials, probably the most important factor in obtaining a good design is obtaining representative samples for use in that design. Without this basic starting point, the design could cause many problems in the field.

All of the methods of design presented, used either the Marshall or Hveem tests to pick the optimum asphalt content in the recycled mix. Since these procedures are the most commonly used methods in designing new mixes, it is helpful in designing recycled mixes due to the familiarity with the tests and the availability of the test equipment.

All of the procedures used the same basic blending chart for determining the correct blend of aged and new asphalt and/or recycling agent to meet the target. Although WisDOT uses penetration grading rather than viscosity grading, the blending charts use the same principles.

The Asphalt Institute and FDOT followed the approach of trying to establish a target percent RAP in the mix prior to selecting the asphalt blend. They then could find out what viscosity of asphalt cement and/or recycling agent was needed to reach the target viscosity. Neither agency seemed to have any hesitancy in using recycling agents in order to meet the target viscosity.

On the other hand, WisDOT started out with trying to pick an asphalt cement to add to the mix which would give an acceptable percent RAP in the mix. They tried to stay away from the use of recycling agents and just use the softer grades of asphalt cement to meet a target penetration. In doing this and establishing a envelope of acceptable percentages of RAP in the mix, they seemed to end up having to pick a point on the edge of their established design envelope in order to get acceptable values for the percent RAP in the mix.

While this approach has indeed worked for WisDOT as evidenced by the large quantities of hot-mix recycling they have accomplished, it is felt that the use of recycling agents could improve their designs. A recycling agent could give them an acceptable design envelope which allows for higher percentages of RAP in the mix.

Each agency examined, cited the fact that they wanted to use the highest percent RAP that would be practical (maximum of 60% for FDOT). While it is true that no American nationwide standards exist for recycling agents at the present time, there are guidelines which do exist. The FDOT has established some standards for recycling agents within their specifications.

The key to the successful use of recycling agents at the present time is gocd quality control. Toward this end, FDOT tests all proposed recycling agents and has established an end-result viscosity specification to control the finished recycled product. It is felt that this is an excellent approach which allows the greatest flexibility in the design of a recycled hot-mix.

Each of the three agencies looked at agreed that the use of milled or processed RAP samples was the preferred approach to obtaining a final mix design. These samples allowed for the ability to get the material properties which would most closely approximate those which would be seen at the plant. The Asphalt Institute recommended that these samples be used whenever possible. The WisDOT uses these samples exclusively in obtaining their final mix designs although, they will start on a project with only preliminary design data on occasion. The FDOT only uses milled or processed RAP for their final mix designs in cases where the contractor is using material from a stockpile, or where the contractor chooses to mill some of the existing roadway to obtain samples, rather than using cores. The approach by The Asphalt Institute could be considered to be in the middle of the road, while FDOT and WisDOT are at farther extremes.

A final mix design with milled or processed RAP would give the best results. The question of how close to that design is it possible to get to if core samples are used, is what must be decided in order to justify their use.

The FDOT required that the RAP be separated by sieving using the 3/4", 1/2", 3/8", No. 4, No. 10 and pan sieves. The gradation of fractions was then calculated. It was this gradation that was used to combine with the new aggregate, rather than the gradation that was found through the extraction tests. The FDOT found that this provided an approximation for the change in gradation that would occur through the milling process. Based on the excellent results obtained by FDOT, there does not seem to be a significant difference between this method and the use of processed or milled RAP samples for the final design. The FDOT does check the extracted gradation of the final recycled product from the plant to insure that the specifications have been met. The field personnel can accept slight variations in gradation from the specification at that point in time, if the Marshall properties justify it.

The FDOT is apparently willing to accept the possible risk their methods bring about. The WisDOT does not take as much risk as FDOT, since they use the milled or processed RAP in their final mix designs. The penalty WisDOT pays is in terms of time on the project. This can correlate into extended construction schedules, increased traffic disruptions, and greater construction costs due to these inefficiencies. When viewed in this manner, maybe the small risks FDOT take in the final mix design process, are very well worthwhile.

The bottom line in hot-mix recycling design, is that adequate procedures exist to design a recycled mix with confidence. This fact is helping states such as Florida to allow new and recycled mix specifications to be combined and the mixes used interchangeably. This allows the contractor the greatest flexibility in choosing his material sources and providing a quality product at the most economical price.

CHAPTER FIVE

VIEW OF A FDOT HOT-MIX RECYCLING PROJECT

INTRODUCTION

This chapter will take a view of an actual FDOT hot-mix recycling project. The project to be looked at was located in Florida's Suwannee County on Interstate 10. The construction was completed by the Sloan Construction Co., Inc., of Live Oak, Florida. The project (number 37120-3423) was started in 1985 and was completed in 1986. The project involved milling approximately 36.5 lane-miles of pavement to a depth of 4 inches. Approximately 85,000 tons of recycled hot-mix were placed on the project.

This chapter will start off by looking at the composition of the existing pavement materials. From there it will review the initial job-mix formula for the project. During the course of the project, the job-mix formula was modified a few times to bring the final viscosity of the recovered asphalt cement in the recycled mix, back into specifications. These changes will be looked at and checked against the resulting changes in the viscosity of the asphalt cement recovered from the recycled mix.

COMPOSITION OF THE EXISTING PAVEMENT MATERIALS

Personnel from District Two of FDOT evaluated the existing pavement and took sufficient samples in accordance with standard FDOT procedures, to obtain a representation of the composition of those materials. The results from the testing of these core samples were compiled into a table for Composition of Existing Pavement for the project. This information then became a part of the contract documents. The basic pieces of information supplied included the ranges and averages for the viscosity, penetration and content of the asphalt cement, and the range and average for the aggregate gradation. This information was broken down by the location in the roadway and the layer in which it was located.

Table 6 shows the actual Composition of Existing Pavement for this project. This information could then be used by any contractors interested in the project to develop a estimated job-mix formula upon which to base their bids. As pointed out in chapter four, FDOT tells the contractors to assume a total asphalt content of 6% for this type of mix for bidding purposes. This is an important factor in making sure that all bids will be based upon the same standards. The contractor is still free to select any percent RAP (up to 60%) that the material properties and his equipment will allow.

The Composition of Existing Pavement information shown in Table 6 shows the variability of the existing pavement materials throughout the project site. The contractor must pay close attention to this variability.

TABLE 6

(FROM FDOT PROJECT 37120-3423)

COMPOSITION OF EXISTING PAVEMENT
I-10, Suwannee County

Project No. 37120-3423
M.P. 5.861 to 14.997
BI 249133

	Westbound Roadway		Eastbound Roadway	
	Top 2.0 Inches		Top 2.0 Inches	
	Range	Average	Range	Average
Viscosity @ 140°F (Poises)	20,494 - 196,720	85,517	19,108 - 64,788	32,852
Penetration @ 77°F (0.1 mm)	14 - 31	22	20 - 33	27
Asphalt Content (%)	6.3 - 6.7	6.5	5.8 - 6.5	6.2
Gradation - Percent Passing				
3/8"	94 - 97	95	94 - 97	96
No. 4	68 - 69	69	62 - 72	66
No. 10	50 - 53	52	43 - 53	48
No. 40	36 - 40	37	33 - 37	35
No. 80	19 - 20	19	19 - 21	20
No. 200	5.3 - 6.2	5.7	5.6 - 7.0	6.4

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT
I-10, Suwannee County

Project No. 37120-3423
M.P. 5.861 to 14.997
BI 249133

	Westbound Roadway		Eastbound Roadway	
	Bottom 2.0 Inches		Bottom 2.0 Inches	
	Range	Average	Range	Average
Viscosity @ 140°F (Poises)	9,365 - 123,604	64,246	5,992 - 141,588	51,824
Penetration @ 77°F (0.1 mm)	17 - 38	25	17 - 46	29
Asphalt Content (%)	4.8 - 5.7	5.0	4.5 - 6.2	5.3
Gradation - Percent Passing				
3/4"	91 - 100	96	87 - 100	96
1/2"	79 - 100	88	71 - 100	90
3/8"	67 - 98	81	64 - 99	83
No. 4	41 - 70	52	39 - 68	54
No. 10	28 - 44	35	27 - 45	35
No. 40	20 - 30	26	20 - 33	27
No. 80	12 - 15	14	14 - 18	16
No. 200	5.7 - 6.0	6.0	5.2 - 7.8	6.0

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT

Project No. 37120-3423
SR-51 (US-129) Under I-10
BI 249133

	Southbound Roadway		Northbound Roadway	
	Range	Average	Range	Average
Viscosity @ 140°F (Poises)	36,531-168,912	102,722	20,281-71,518	45,[illegible]
Penetration @ 77°F (0.1 mm)	14 - 28	21	21 - 33	27
Asphalt Content (%)	5.3 - 6.1	5.6	5.4 - 6.1	5.7
Gradation - Percent Passing				
3/4"	96 - 100	98	93 - 97	95
1/2"	84 - 88	85	85 - 85	85
3/8"	78 - 85	80	79 - 80	80
No. 4	47 - 53	50	47 - 50	48
No. 10	32 - 34	33	31 - 33	32
No. 40	25 - 26	26	26 - 27	27
No. 80	14 - 17	16	15 - 18	17
No. 200	4.9 - 6.5	5.6	4.5 - 7.7	6.0
Total Pavement Thickness (In.)	3.0 - 3.2	3.1	2.9 - 3.[illegible]	3.2
Thickness Evaluated (In.)	(TOP)	2.5	(TOP)	2.5

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT

SR -10 (US-90) Under I-10
Project No. 37120-3423
BI 249133

	Westbound Roadway		Eastbound Roadway	
	Range	Average	Range	Average
Viscosity @ 140°F (Poises)	158,424 - 1,656,897	907,661	62,424 - [illegible]	[illegible]
Penetration @ 77°F (0.1 mm)	5 - 22	14	12 - 22	[illegible]
Asphalt Content (%)	4.6 - 5.2	4.9	5.1 - 5.8	5.4
Gradation - Percent Passing				
3/4"	94 - 97	95	--- - ---	100
1/2"	85 - 96	89	--- - ---	100
3/8"	80 - 82	81	99 - 100	100
No. 4	54 - 56	55	66 - 69	68
No. 10	34 - 36	35	40 - 45	43
No. 40	25 - 27	26	28 - [illegible]	29
No. 80	14 - 15	15	15 - 16	15
No. 200	4.3 - 5.9	5.4	4.2 - 4.9	[illegible]
Total Pavement Thickness (In.)	3.3 - 3.6	3.4	2.8 - 3.4	[illegible]
Thickness Evaluated (In.)	(TOP)	2.5	(TOP)	[illegible]

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT
Project No. 37120-3423
US-129 and I-10 Ramps
BI 249133

	Westbound Ramps		Eastbound Ramps	
	Bottom 2.0 Inches		Bottom 2.0 Inches	
	On Ramp	Off Ramp	On Ramp	Off Ramp
	Average	Average	Average	Average
Viscosity @ 140°F (Poises)	132,431	111,989	305,424	[illegible]
Penetration @ 77°F (0.1 mm)	18	17	14	34
Asphalt Content (%)	4.6	4.6	4.7	4.8
Gradation - Percent Passing				
1"	100	97	100	100
3/4"	91	90	92	90
1/2"	73	71	73	71
3/8"	65	64	65	63
No. 4	36	38	39	36
No. 10	26	27	28	26
No. 40	22	24	24	22
No. 80	18	14	15	15
No. 200	5.6	4.5	8.6	9.2

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT

US-129 and I-10 Ramps
Project No. 37120-3423
BI 249133

	Westbound Ramps Top 2.0 Inches		Eastbound Ramps Top 2.0 Inches	
	On Ramp	Off Ramp	On Ramp	Off Ramp
	Average	Average	Average	Average
Viscosity @ 140°F (Poises)	62,590	185,561	139,234	152,513
Penetration @ 77°F (0.1 mm)	22	16	18	15
Asphalt Content (%)	6.1	5.7	5.8	6.0
Gradation - Percent Passing				
1/2"	100	100	100	100
3/8"	97	100	100	98
No. 4	64	70	72	64
No. 10	42	41	40	41
No. 40	33	31	28	31
No. 80	18	16	16	18
No. 200	4.9	4.9	5.3	6.0

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT

US-90 and I-10 Ramps
Project No. 37120-3423
BI 249133

	Westbound Ramps		Eastbound Ramps	
	Bottom 2.0 Inches		Bottom 2.0 Inches	
	On Ramp	Off Ramp	On Ramp	Off Ramp
	Average	Average	Average	Average
Viscosity @ 140°F (Poises)	13,357	61,263	117,612	26,303
Penetration @ 77°F (0.1 mm)	38	21	17	29
Asphalt Content (%)	4.9	5.4	4.7	5.0
Gradation - Percent Passing				
1"	100	100	96	100
3/4"	88	91	78	86
1/2"	77	71	59	71
3/8"	70	63	52	65
No. 4	45	40	33	40
No. 10	32	29	25	29
No. 40	24	22	19	22
No. 80	15	14	12	13
No. 200	7.2	6.9	5.5	6.6

TABLE 6 (CONTINUED)

COMPOSITION OF EXISTING PAVEMENT

Project No. 37120-3423
US-90 and I-10 Ramps
BI 249133

	Westbound Ramps		Eastbound Ramps	
	Top 2.0 Inches		Top 2.0 Inches	
	On Ramp Average	Off Ramp Average	On Ramp Average	Off Ramp Average
Viscosity @ 140°F (Poises)	37,293	25,499	80,807	87,468
Penetration @ 77°F (0.1 mm)	25	29	20	20
Asphalt Content (%)	6.1	6.0	5.9	6.3
Gradation - Percent Passing				
1/2"	100	100	100	100
3/8"	97	97	96	97
No. 4	66	65	67	77
No. 10	41	42	44	42
No. 40	30	32	31	29
No. 80	19	19	17	16
No. 200	5.3	6.0	5.2	5.2

THE PROJECT JOB-MIX FORMULA

The Sloan Construction Co., Inc., of Live Oak, Florida, was the successful contractor who bid on this project. Figure 9 shows the initial job-mix formula which was approved for this project as of August 5, 1985. It shows that the contractor planned to use 60% RAP in the mix. The job-mix formula also shows the Marshall mix design properties for the optimum asphalt content of 6%. This optimum asphalt content was determined through the use of the standard Marshall mix design procedures (as outlined in chapter four under FDOT mix design procedures), and is not just the estimated asphalt content as used for bidding purposes. In this case, they just happened to be the same.

A High Maltene Asphalt (HMA) with a viscosity of 200 poises was chosen as the recycling agent for the recycled mix. This viscosity was determined through the use of a nomograph similar to the one shown in Figure 4 (chapter four).

Figure 10 shows a revision to the initial job-mix formula on September 3, 1985. The reasons for this revision were that the mix temperature was being changed from 285 deg F to 300 deg F, and the gradation of the milled material on the 3/8" sieve had changed slightly from what had been calculated previously. This change was made just prior to the start of paving operations and represented the actual conditions at the plant.

FIGURE 9 - INITIAL JOB-MIX FORMULA

(FROM FDOT PROJECT 37120-3423)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

Submit to the State Materials and Research Engineer, Central Bituminous Laboratory, P. O. Box 1029, Gainesville, Florida 32602.

Project No. 37120-3423 Type Mix S-1 Recycle Date 7/22/85

Road No. 8 (I-10) County Suwannee District 2

Contractor Name & Plant Location Sloan Const. Co., Inc. - Live Oak, FL Phone 904-289-7191

Intended Use of Mix Surface Submitted By Sloan Const. QA Tech. W. M. Philbeck

TYPE MATERIAL	PRODUCER	PIT NO.	DATE SAMPLED	LAB NO.
1. Milled Mat'l	37120 - 3423 Top 4.0" I-10 EB & WB Lanes	RDWY	7/22/85	
2. 3/8" Stone	Vulcan Mat'ls	AL-149	7/22/85	
3. Conc. Sand	Rountree Constr. Co.	GA-303	7/22/85	
4.				
5.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	BLEND	60 %	20 %	20 %	%	%	JOB MIX	SPECIFICATION
	Number	1	2	3	4	5	FORMULA	RANGE
SIEVE SIZE	3/4	100	100	100			100	100
	1/2	98	100	100			99	88-100
	3/8	92	98	100			95	75-93
	No. 4	71	47	100			72	47-75
	No. 10	53	8	95			52	31-53
	No. 40	41	4	34			32	19-35
	No. 80	27	3	4			18	7-21
	No. 200	11.2	1.1	0.5			7.0	2-7
	Sp. Gr.	2.534	2.741	2.637			2.593	

R-83-37-160(TS-1)

MATERIALS DIVISION USE ONLY

cc: Mr. R. D. Buser
Mr. W. H. Skinner
Mr. R. O. Humphreys (2)
Mr. D. R. Turner
Mr. G. E. Pettyjohn
Sloan Constr. Co. (2)
Cen Bit Lab (2)
Bit. Rch Lab (2)
Project File

clj

State Materials & Research Engineer

Effective Date 8/5/85

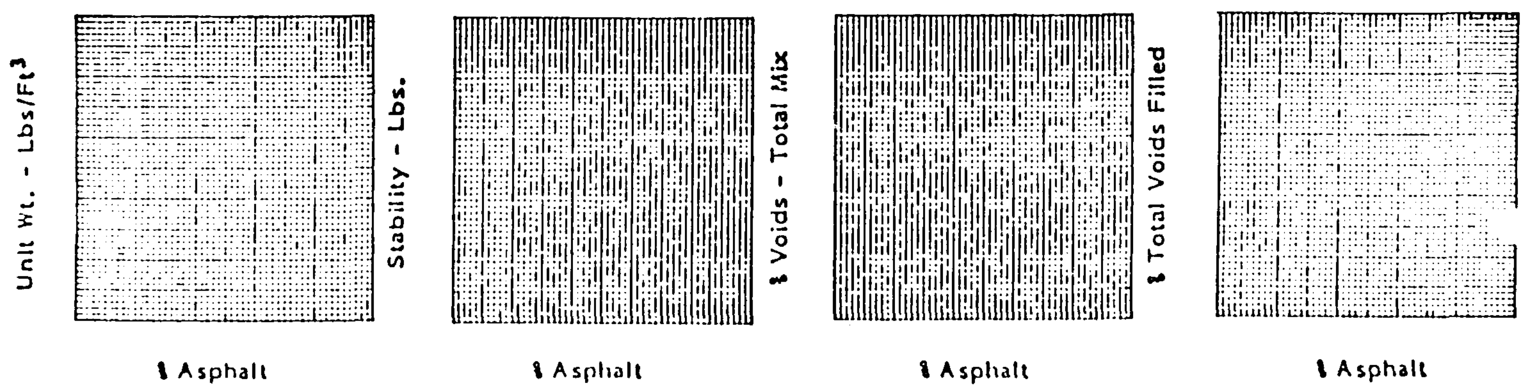
Copies: District Bituminous Engineer

FIGURE 9 (CONTINUED)

HOT MIX DESIGN DATA SHEET†

R-83-37-160 (TS-1)

Percent A.C. Total Wt. of Mix	Bulk Sp. Gr. of Compacted Mix	Max. Meas. Sp. Gr. of Compacted Mix	Air Voids Percent	V.M.A. Percent	Voids Filled Percent	Effective Asphalt Content	Adjusted Stability Averaged	Flow Average
6.0	2.325	2.397	3.0	15.7	80.9	5.6	1893	12



Optimum Asphalt 6.0 %

Lab. Density 145.1 Lbs/Ft³

Stability 1893 Lbs.

V.M.A. 15.7 %

Air Voids 3.0 %

Voids Filled 80.9 %

Mixing Temperature 285 °F

Additives 0.5 antistrip %

Optimum Asphalt = 6.0%

Asphalt using 0 % Milled Material @5.8 % = 3.5%

To Be Added = 2.5%

IMA 200

FIGURE 10 - JOB-MIX FORMULA REVISED ON 9/3/85

(FROM FDOT PROJECT 37120-3423)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

Submit to the State Materials and Research Engineer, Central Bituminous Laboratory, P. O. Box 1029, Gainesville, Florida 32602.

Project No. 37120-3423 Type Mix S-1 Recycle Date 7/22/85

Road No. 8 (I-10) County Suwannee District 2

Contractor Name & Plant Location Sloan Const. Co., Inc. - Live Oak, FL Phone 904-289-7191

Intended Use of Mix Surface Submitted By Sloan Const. QA Tech. W. M. Philbeck

TYPE MATERIAL	PRODUCER	PIT NO.	DATE SAMPLED	LAB NO.
1. Milled Mat'l	37120-3423 Top 4.0" EB & WB I-10	RDWY	7/22/85	
2. 3/8" Stone	Vulcan Mat'ls	AL-149	7/22/85	
3. Conc. Sand	Rountree Construction Co.	GA-303	7/22/85	
4.				
5.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	BLEND	60 %	20 %	20 %	%	%	JOB MIX	SPECIFICATION
	Number	1	2	3	4	5	FORMULA	RANGE
SIEVE SIZE	3/4	100	100	100			100	100
	1/2	98	100	100			99	88-100
	3/8	89	98	100			93	75-93
	No. 4	71	47	100			72	47-75
	No. 10	53	8	95			52	31-53
	No. 40	41	4	34			32	19-35
	No. 80	27	3	4			18	7-21
	No. 200	11.2	1.1	0.5			7.0	2-7
	Sp. Gr.	2.534	2.741	2.637			2.593	

R-83-37-160(Rev. 9-3-85)(TS-1)
Rev. to reflect change of mixing temp., & gradation of mill matl's. on # 3/8 sieve.

MATERIALS DIVISION USE ONLY

cc: Mr. R. D. Buser
Mr. W. H. Skinner
Mr. R. O. Humphreys (2)
Mr. D. R. Turner
Mr. G. E. Pettyjohn
Sloan Constr. Co. (2)
Cen Bit Lab (2)
Bit. Rch Lab (2)
Project File

State Materials & Research Engineer

Effective Date 8/5/85

Copies: District Bituminous Engineer

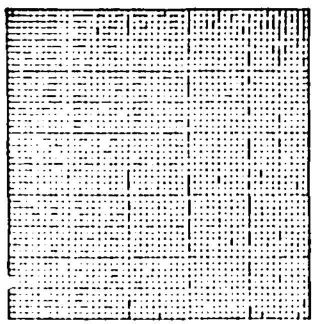
jh

FIGURE 10 (CONTINUED)

R-83-37-160 (Rev. 9-3-85)(TS-1)

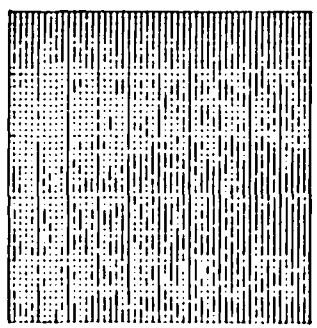
Percent A.C. Total Wt. of Mix	Bulk Sp. Gr. of Compacted Mix	Max. Meas. Sp. Gr. of Compacted Mix	Air Voids Percent	V.M.A. Percent	Voids Filled Percent	Effective Asphalt Content	Adjusted Stability Averaged	Flow Average
6.0	2.325	2.397	3.0	15.7	80.9	5.6	1893	12

Unit Wt. - Lbs/Ft³



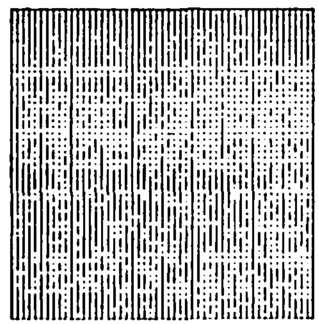
% Asphalt

Stability - Lbs.



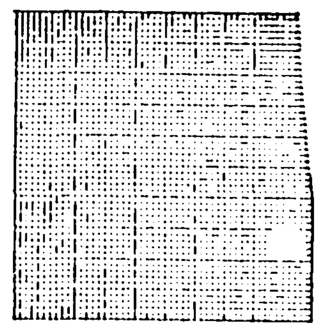
% Asphalt

% Voids - Total Mix



% Asphalt

% Total Voids Filled



% Asphalt

Optimum Asphalt 6.0 %

Lab. Density 145.1 Lbs/Ft³

Stability 1893 Lbs.

V.M.A. 15.7 %

Air Voids 3.0 %

Voids Filled 80.9 %

Mixing Temperature 300° °F

Additives 0.5 antistrip %

Optimum Asphalt = 6.0%

Asphalt using 60 % Milled Material @5.8 % = 3.5%

To Be Added = 2.5%

HMA 200

CONTROL OF THE JOB-MIX FORMULA

The FDOT checks the quality of the recycled mix in a number of different ways. The contractor must have a quality control technician who holds a valid certificate of qualification from FDOT. The gradation of the new aggregate is checked on a frequency of approximately once per thousand tons. The aggregate gradation in the RAP is also checked after it has been extracted. Mix temperatures are checked. The aggregate gradation of the recycled mix is checked once per day after extraction. Samples are also taken once per day at the plant to run Marshall tests and to be sent out for checking the resulting viscosity of the asphalt cement in the recycled mix. The viscosity tests are normally done by the FDOT Bureau of Materials and Research, located in Gainesville, Florida, at a frequency of approximately once per 2000 tons of recycled mix.

In this project, meeting the end-result viscosity specification of 4500 $\pm$ 1500 poises, was the most significant factor that required changes in the job-mix formula. Table 7 shows the record of end-result viscosity quality control tests on FDOT project 37120-3423. This table also shows the points at which changes were made in the job-mix formula. The resulting changes in the end-result viscosity of the mix can then be readily reviewed.

Figures 11, 12 and 13 show the documentation for the changes in the job-mix formula outlined in Table 7.

TABLE 7

RECORD OF END RESULT VISCOSITY QUALITY CONTROL TESTS

(FROM FDOT PROJECT 37120-3423)

DATE SAMPLED	PENETRATION	VISCOSITY	CUMULATIVE TONS
9/6/85	44	6,860	1,550
9/10/85	38	9,291	2,373
9/16/85	37	9,558	4,100
9/19/85	36	11,312	7,000

Job-mix formula revised on 10/2/85 to reflect a change in the viscosity of the recycling agent from 200 to 100.

DATE SAMPLED	PENETRATION	VISCOSITY	CUMULATIVE TONS
10/17/85	48	6,958	9,800
10/24/85	51	4,466	12,500
10/28/85	62	3,034	15,400
11/04/85	60	3,035	17,200

Job-mix formula revised on 11/7/85 to reflect a change in the mixing temperature from 300 deg F to 285 deg F.

DATE SAMPLED	PENETRATION	VISCOSITY	CUMULATIVE TONS
11/08/85	invalid test results		22,100
11/13/85	54	4,242	24,100
11/15/85	71	2,429	27,700
11/19/85	61	3,369	29,700
11/21/85	50	4,367	32,100
11/26/85	47	5,478	33,900
12/03/85	62	2,573	36,900
12/05/85	59	3,022	38,700
12/07/85	76	4,101	40,900
12/11/85	48	5,104	42,800

TABLE 7 (CONTINUED)

DATE SAMPLED	PENETRATION	VISCOSITY	CUMULATIVE TONS
12/16/85	40	7,442	45,300
12/18/85	48	5,209	47,200
1/13/86	37	12,108	50,200
1/16/86	33	13,939	52,450
1/21/86	41	7,763	54,100

Job-mix formula revised on 1/27/86 to reflect a change in the percent RAP in the mix from 60% to 55%.

DATE SAMPLED	PENETRATION	VISCOSITY	CUMULATIVE TONS
1/29/86	54	4,297	56,200
1/31/86	50	5,480	58,600
2/03/86	47	5,746	60,400
2/05/86	45	7,167	62,500
2/13/86	57	3,560	64,500
2/19/86	37	12,308	66,300
2/21/86	41	6,888	68,100
3/08/86	55	4,057	80,200
3/11/86	53	4,500	81,800

FIGURE 11 - JOB-MIX FORMULA REVISED ON 10/2/85

(FROM FDOT PROJECT 37120-3423)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

Submit to the State Materials and Research Engineer, Central Bituminous Laboratory, P. O. Box 1029, Gainesville, Florida 32602

Project No. 37120-3423 Type Mix S-1 Recycle Date 7/22/85

Road No. 8 (I-10) County Suwannee District 2

Contractor Name & Plant Location Sloan Const. Co., Inc. - Live Oak, FL Phone 904-289-7191

Intended Use of Mix Surface Submitted By Sloan Const. QA Tech. W. M. Philbeck

TYPE MATERIAL	PRODUCER	PIT NO.	DATE SAMPLED	LAB NO.
1. Milled Mat'l	37120-3423 Top 4.0" EB & WB I-10	RDWY	7/22/85	
2. 3/8" Stone	Vulcan Mat'ls	AL-149	7/22/85	
3. Conc. Sand	Rountree Construction Co.	GA-303	7/22/85	
4.				
5.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	BLEND	60 %	20 %	20 %	%	%	JOB MIX FORMULA	SPECIFICATION RANGE
	Number	1	2	3	4	5		
SIEVE SIZE	3/4	100	100	100			100	100
	1/2	98	100	100			95	83-100
	3/8	89	98	100			93	75-93
	No. 4	71	47	100			72	47-75
	No. 10	53	8	95			52	31-53
	No. 40	41	4	34			32	19-35
	No. 80	27	3	4			18	7-21
	No. 200	11.2	1.1	0.5			7.0	2-7
	Sp. Gr.	2.534	2.741	2.637			2.593	

R-83-37-160 (Rev. 9-3-85) (Rev. 10-2-85) (TS-1)

Rev. to reflect change in recycling agent from HMA 200 to HMA 100.

MATERIALS DIVISION USE ONLY

cc: Mr. R. D. Buser
Mr. W. H. Skinner
Mr. R. O. Humphreys (2)
Mr. D. R. Turner
Mr. G. E. Pettyjohn
Sloan Constr. Co. (2)
Cen Bit Lab (2)
Bit. Rch Lab (2)
Project File

State Materials & Research Engineer

Effective Date 10-2-85

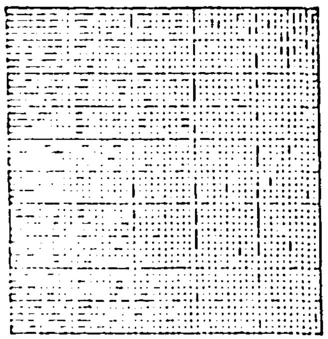
Copies: District Bituminous Engineer

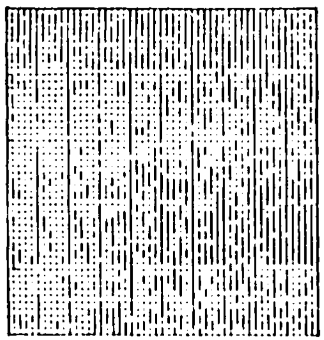
jh

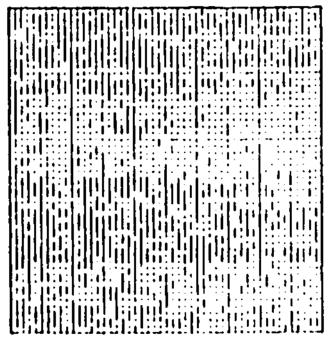
FIGURE 11 (CONTINUED)

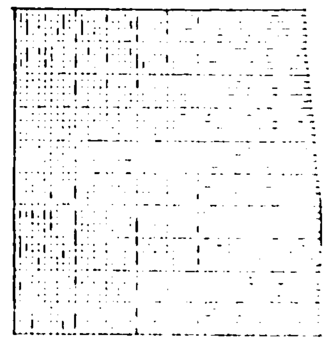
R-63-37-160 (Rev. 9-3-85) (Rev. 10-2-85) (TS-1)

Percent A.C. Total Wt. of Mix	Bulk Sp. Gr. of Compacted Mix	Max. Meas. Sp. Gr. of Compacted Mix	Air Voids Percent	V.M.A. Percent	Voids Filled Percent	Effective Asphalt Content	Adjusted Stability Averaged	Flow Average
6.0	2.325	2.397	3.0	15.7	80.9	5.6	1893	12









Optimum Asphalt 6.0 %

Lab. Density 145.1 Lbs/Ft^3

Stability 1893 Lbs.

V.M.A. 15.7 %

Air Voids 3.0 %

Voids Filled 80.9 %

Mixing Temperature ~~285~~ 300 °F

Additives 0.5 antistrip %

Optimum Asphalt = 6.0%

Asphalt using 60 % Milled Material @ 5.6 % = 3.5%

HMA 100 To Be Added = 2.5%

FIGURE 12 - JOB-MIX FORMULA REVISED ON 11/7/85

(FROM FDOT PROJECT 37120-3423)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

[illegible]

Project No. 37120-3423 Type Mix S-1 Recycle Date 7-22-85

Road No. 8 (I-10) County Suwannee District 2

Contractor Name & Plant Location Sloan Const. Co., Inc. - Live Oak, FL Phone (904) [illegible]

Intended Use of Mix Surface Submitted By Sloan Const. QA Tech. W. M. [illegible]

TYPE MATERIAL	PRODUCER	PIT NO.	DATE SAMPLED	LAB NO.
1. Milled Material	37120-3423 TOP 4.0 EB & WB I-10	Roadway	7/22/85	
2. 3/8" Stone	Vulcan Materials	AL-149	7/22/85	
3. Conc. Sand	Rountree Construction Co.	GA-303	7/22/85	
4.				
5.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	BLEND	60 %	20%	20%	%	%	JOB MIX	SPECIFICATION
	Number	1	2	3	4	5	FORMULA	RANGE
SIEVE SIZE	3/4	100	100	100			100	100
	1/2	98	100	100			99	88 - 100
	3/8	89	98	100			93	75 - 93
	No. 4	71	47	100			72	47 - 75
	No. 10	53	8	95			52	31 - 53
	No. 40	41	4	34			32	19 - 35
	No. 80	27	3	4			18	7 - 21
	No. 200	11.2	1.1	0.5			7.0	2 - 7
	Sp. Gr.	2.534	2.741	2.637			2.593	

R-83-37-160 (Rev. 9-3-85) (Rev. 10-2-85)
(Rev. 11-7-85) (TS-1)

MATERIALS DIVISION USE ONLY

Rev. to reflect change in mixing temp. from 300^0 to 285^0.
THIS CORRECTED REPORT CANCELS & SUPERCEDES ORIGINAL REPORT DUE TO EXCLUSION OF Rev. (10-2-85)

c: Mr. R. D. Buser
Mr. W. H. Skinner
Mr. R. O. Humphreys (2)
Mr. D. R. Turner
Mr. G. E. Pettyjohn
Sloan Construction (2)
Con Bit Lab (2)
Bit Res Lab (2)
Project File

State Materials & Research Engineer

Effective Date 11-7-85

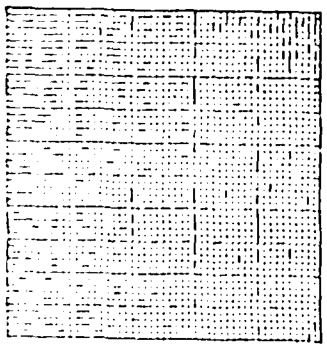
Copies: District Bituminous Engineer

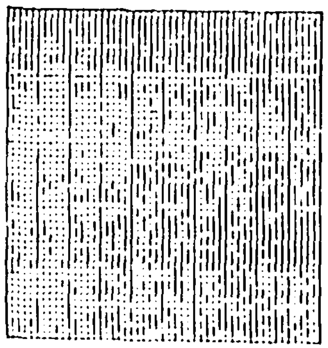
jh

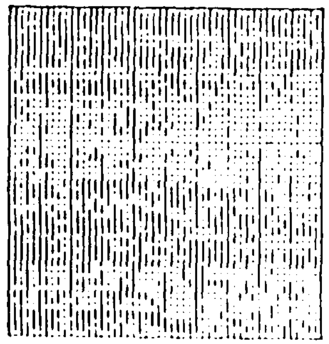
FIGURE 12 (CONTINUED)

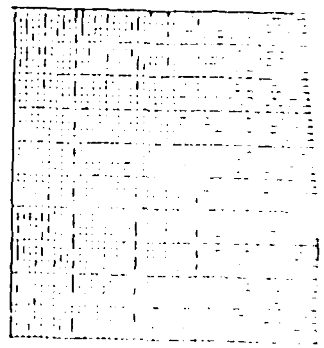
R-83-37-160 (Rev. 9-3-85) (Rev. 10-2-85) (Rev. 11-7-85) (TS-1)

Percent A.C. Total Wt. of Mix	Bulk Sp. Gr. of Compacted Mix	Max. Meas. Sp. Gr. of Compacted Mix	Air Voids Percent	V.M.A. Percent	Voids Filled Percent	Effective Asphalt Content	Adjusted Stability Averaged	Flow Average
6.0	2.325	2.397	3.0	15.7	80.9	5.6	1893	12









Optimum Asphalt 6.0 %

Lab. Density 145.1 Lbs/Ft^3

Stability 1893 Lbs.

V.M.A. 15.7 %

Air Voids 3.0 %

Voids Filled 80.9 %

Mixing Temperature 285 °F

Additives 0.5 antistrip %

Optimum Asphalt = 6.0%
Asphalt using 60 % Milled Material @5.8% = 3.5%
HMA 100 To Be Added = 2.5%

FIGURE 13 - JOB-MIX FORMULA REVISED ON 1/27/86

(FROM FDOT PROJECT 37120-3423)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

Submit to the State Materials and Research Engineer, Central Bituminous Laboratory, P. O. Box 1029, Gainesville, Florida 32602.

Project No. 37120-3423 Type Mix S-1 Recycle Date 7/22/85

Road No. 8 (I-10) County Suwannee District 2

Contractor Name & Plant Location Sloan Const. Co., Inc. - Live Oak, FL Phone (904) 289-7191

Intended Use of Mix Surface Submitted By Sloan Const. QA Tech. W. M. Philbeck

TYPE MATERIAL	PRODUCER	PIT NO.	DATE SAMPLED	LAB NO.
1. Milled Material	37120-3423 TOP 4.0" EB & WB I-10	Roadway	7/22/85	
2. 3/8" Stone	Vulcan Materials	AL-149	7/22/85	
3. Conc. Sand	Rountree Construction Co.	GA-303	7/22/85	
4.				
5.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	BLEND	55 %	25 %	20 %	%	%	JOB MIX FORMULA	SPECIFICATION RANGE
	Number	1	2	3	4	5		
SIEVE SIZE	3/4	100	100	100			100	100
	1/2	98	100	100			99	88 - 100
	3/8	89	98	100			93	75 - 93
	No. 4	71	47	100			71	47 - 75
	No. 10	53	8	95			50	31 - 53
	No. 40	41	4	34			30	19 - 35
	No. 80	27	3	4			16	7 - 21
	No. 200	11.2	1.1	0.5			6.5	2 - 7
	Sp. Gr.	2.534	2.741	2.637			2.603	

R-83-37-160 (Rev. 9-3-85) (Rev. 10-2-85) (Rev. 11-7-85) (Rev. 1-27-86) (TS-1)

MATERIALS DIVISION USE ONLY

Mr. R. D. Buser
Mr. W. H. Skinner
Mr. R. D. Humphreys (2)
Mr. D. R. Turner
Mr. G. E. Pettyjohn
Sloan Construction (2)
Cen Bit Lab (2)
Bit Res Lab (2)
Project File

jh

Rev. to reflect change of blend.

State Materials & Research Engineer

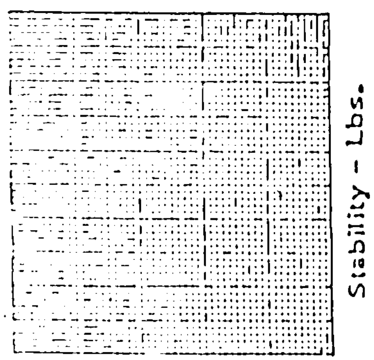
Effective Date 1-27-86

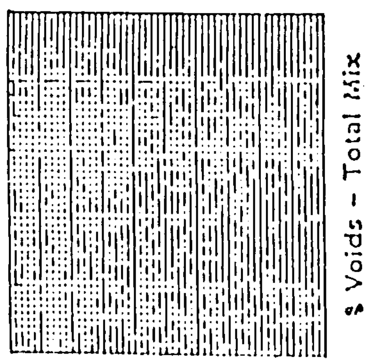
Copies: District Bituminous Engineer

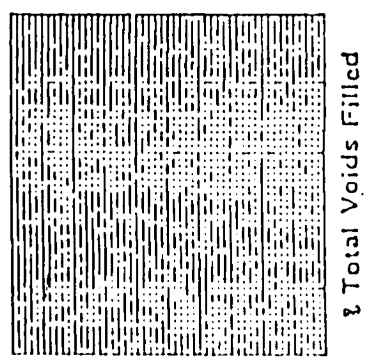
FIGURE 13 (CONTINUED)

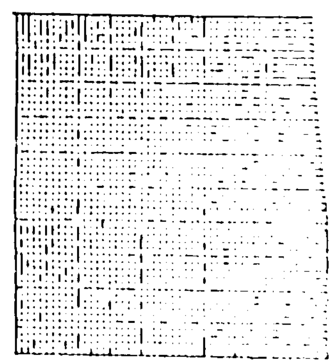
R-83-37-160 (Rev. 9-3-85) (Rev. 10-2-85) (Rev. 11-7-85) (Rev. 1-27-86)(TS-1)

Percent A.C. Total Wt. of Mix	Bulk-Sp. Gr. of Compacted Mix	Max. Meas. Sp. Gr. of Compacted Mix	Air Voids Percent	V.M.A. Percent	Voids Filled Percent	Effective Asphalt Content	Adjusted Stability Averaged	Flow Average
6.0	2.325	2.397	3.0	16.0	81.3	5.8	1893	12









Optimum Asphalt 6.0 % V.M.A. 16.0 % Mixing Temperature 285 °F

Lab. Density 145.1 Lbs/Ft^3 Air Voids 3.0 % Additives 0.5 antistrip %

Stability 1893 Lbs. Voids Filled 81.3 %

Optimum Asphalt = 6.0%
Asphalt using 55 % Milled Material @5.8 % = 3.2%
NMA 100 To Be Added = 2.8%

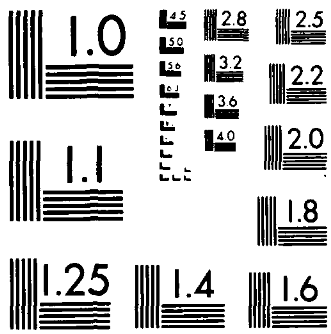
The changes in the job-mix formula shown in figures 11 and 13 represent two basic methods of changing the end-result viscosity of the recovered asphalt cement in the recycled mix. In Figure 11, the viscosity of the recycling agent was changed from 200 poises to 100 poises. This change was required because the viscosity of the recovered asphalt cement was staying consistently higher than the specifications allowed. As can be seen from Table 7, this change resulted in the end-result viscosity being slightly higher than the specifications on the next test and then within the specifications for most of the next 35,000 tons of recycled mix.

Figure 13 showed a change in the job-mix formula from using 60% to 55% RAP. This change became required when the end-result viscosity of the recovered asphalt cement stayed higher than the specification for three consecutive tests. The lowest viscosity recycling agent available was 100 poises and it was already being used. In order to reduce the end-result viscosity, it then became necessary to reduce the percent RAP in the mix. This resulted in a higher percentage of the 100 poise recycling agent in the mix and therefore the overall viscosity was reduced. Table 7 showed that this change was very effective in getting the recycled mix [illegible] into the end-result viscosity specification range.

The change in the job-mix formula shown in Fig [illegible] a change in the mix temperature from 300 deg F [illegible]

AD-A184 199 ASPHALT HOT-MIX RECYCLING(U) FLORIDA UNIV GAINESVILLE 2/2
D L WATTS 1987 N00228-85-G-3323

UNCLASSIFIED F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 7 shows that this change did not have any significant effect on the final viscosity of the asphalt cement in the recycled mix though. In general it could be expected that a reduction in the mix temperature would result in a lowering of the viscosity of the asphalt cement since it would lose a smaller amount of volatiles.

CONCLUSION

The data presented in this chapter points out a number of important factors in the hot-mix recycling process. The data is all from an actual FDOT project and illustrates real life problems and solutions.

The Composition of Existing Pavement data presented in the FDOT recycling contracts will show the variability of the existing pavement materials across the project site. This information must be representative of that project site in order to allow the contractors to prepare an accurate bid. It also allows for the basis of a more rational mix design when the ranges and averages of the existing pavement material properties are known.

Although no Marshall test data for the control of the quality of the recycled mix was presented in this chapter, it was the end-result viscosity of the recovered asphalt cement which in fact had the major impact on changes in the job-mix formula. During this project, FDOT was using an end-result viscosity specification of 4500 ± 1500 poises. In 1986 this specification was changed to 6000 ± 2000 poises.

There are a number of reasons for this change in the end-result viscosity specification. Probably the main reason is that the original specification was more restrictive than if new materials had been used in the mix. The normal asphalt cement used in Florida has been AC-20. The viscosity of AC-20 is approximately 2000 poises. The FDOT allows a viscosity ratio of 4 to 1 for asphalt cement. This would result in the AC-20 having up to a viscosity of 8000 poises after the Thin Film Oven Test (TFOT). With this in mind, it would not make a lot of sense to have to keep the end-result viscosity of the asphalt cement recovered from a recycled mix to a maximum of only 6000 poises. Therefore the change in specification brings both the new and recycled mixes into closer agreement on specification requirements.

The FDOT project 37120-3423 demonstrated two of the basic methods for controlling the quality of recycled mix through an end-result viscosity specification. To change the end result viscosity of the recycled mix, either the viscosity of the recycling agent must be altered, or the percentage of RAP in the mix must be altered. This project demonstrated that if the viscosity of the recycling agent can not be reduced enough to obtain the desired end-result viscosity, then the percentage of RAP must be reduced.

The aggregate gradations and Marshall properties of the recycled mix are relatively easy to control and check at the plant site. At the present time FDOT checks the end-result viscosity of the asphalt cement in the recycled mix at their central lab at the Bureau of Materials and Research located in Gainesville. This creates a problem in getting test results back to the plant site in sufficient time to allow problems to be corrected. By the time enough test results are known to establish the fact that a change is required, a lot of tons of recycled mix will have gone through the plant and be in place.

This problem may not be as large as it may seem at first though. The mix properties as tested at the plant with the Marshall apparatus are known very quickly and will alert the on site personnel that a problem may be or already has developed. The recycled mix with a binder of slightly higher viscosity than desired will still provide many years of excellent service. The test results for the end result viscosity will still be known in sufficient time by FDOT to keep a large problem from going uncorrected.

CHAPTER SIX

HOT-MIX RECYCLING EQUIPMENT CONSIDERATIONS

INTRODUCTION

Hot-mix recycling requires some differences in equipment as compared to the use of asphalt concrete mixes made of all new materials. This chapter is not meant to be a detailed analysis of all construction equipment makes, models, capabilities, production rates, etc., which can be utilized in the hot-mix recycling process. Instead, it concentrates on presenting an overview of the equipment considerations which are required by the hot-mix recycling process.

Equipment for hot-mix recycling can be looked at as being divided into three categories as follows:

1. Removal and sizing
2. Reprocessing
3. Laydown and compaction

REMOVAL AND SIZING

The first consideration is the removal and sizing of the existing asphalt pavement material. There are two basic methods for doing this. The first is to rip and crush the pavement and the second is milling.

RIP AND CRUSH

In this operation, scarifiers, grid rollers, or rippers are used to break up the pavement. The broken up pavement material is then loaded into trucks and hauled to a central location. The material can either be stockpiled for future use or crushed and recycled right away.

This method is primarily used when the existing pavement is in such poor condition that the entire pavement section requires reconstruction. It could also be used when the existing base must be replaced or reworked, where an existing roadway is to be abandoned or realigned, where very hard aggregate makes milling impractical, or even where an asphalt overlay is being removed from an existing concrete pavement.

The drawbacks over milling include the fact that there is increased traffic disruption, the material still must be crushed in order to obtain appropriate sizing, it is not well suited to remove only a portion of the pavement, and if the base is to remain in place this method will require some rework of the surface of that base.

The advantages it has over milling include the speed of removal of material from the project site and the fact that it requires less sophisticated equipment and is therefore less likely to be delayed by equipment breakdowns.

The pavement material broken up in this method must be crushed and screened. Generally it is desired that the maximum particle size be no more than 2 inches in diameter. This will allow for proper mixing to take place in the plant. The crushing process must be careful that it minimizes the increase in fine material or fracture new faces on the coarse aggregate. The increased fines and new fractured faces would require more new asphalt cement and virgin aggregate in the mix. None of the fines that exist in the material should be lost in the operation since they will contain a large portion of the reclaimed asphalt cement.

MILLING

Milling is best used on projects where only partial removal of the existing pavement is required, where minimized traffic disruptions are called for, or where the existing base is to be kept intact. Milling has the capability to remove and size the pavement material in one operation.

Milling machines usually employ a rotating drum with special teeth to cut the pavement to a predetermined depth and size. Single pass cutting widths of up to 12 feet and depths of over 4 inches are possible depending upon the design of the machine and the properties of the existing pavement material.

The size of the milled product will depend on a number of factors such as the number, type, arrangement, and condition of the cutting teeth, the forward speed of the machine, the depth of cut and the properties of the existing pavement material. The milling operation will alter the gradation of the aggregate by increasing the percentage of fine material. This must then be compensated through the gradation of the new aggregate to be added to the mix. A small percentage of oversized chunks will result as well and these must be scalped off before entering the plant.

The milling of just one lane followed by the paving operation will minimize the potential for leaving long stretches of milled pavement open to traffic if delays occur. If the milled thickness of the single lane exceeds 1 1/2 inches, there will be the additional benefit of better compaction at the joint due to the lateral restraint provided by the other lane.

REPROCESSING

This section will discuss the stockpiling and handling of the milled or processed RAP as well as the types of plants used in the hot-mix recycling process. The two most common types of plants used are the batch plant and the drum mix plant.

STOCKPILING AND HANDLING OF RAP

The height of the stockpile of RAP should be limited to a maximum of about 10 feet. This will help to minimize the material from sticking together due to dead load and high ambient air temperatures. Additionally, loaders, dozers and trucks should not be allowed on the stockpile for the same basic reason.

The RAP should also be protected from the weather to help prevent unwanted moisture from being absorbed. Often times it would be wise to provide a protective covering over the stockpile. Another very effective method to help minimize moisture gain and excessive sticking, is to coordinate the crushing or milling and the hot-mixing operations so that the size of the stockpile is kept to a minimum.

BATCH PLANTS

The technique used by batch plants in the hot-mix recycling process is known as the heat transfer method. The following is a brief outline of how the batch plant operates when producing recycled mixes.

The new aggregate is proportioned in the cold feed bins and is dried in a conventional aggregate dryer. From there the new aggregate is conveyed to the hot storage bins. So far this is the same as for new mixes except that the aggregate is superheated.

The RAP is transferred from the stockpile to a separate cold feed bin which has very steep sides. Generally no heating or drying of the RAP is done at this point. The RAP is then conveyed to the weigh hopper where it joins with the superheated new aggregate. Heat transfer then takes place as the proportioned materials are dropped into the pugmill. The recycled mix does not normally reach full temperature equilibrium until after it leaves the pugmill. A surge bin or storage silo help insure that this equilibrium is reached.

The amount of RAP that can be used in the recycled mix depends on the moisture content and stockpile temperature of the RAP, the required final temperature of the recycled mix, and the temperature of the superheated aggregate. If conditions are such that the moisture content of the RAP is very low and the ambient air temperatures are high, up to 50 percent RAP can be used. A practical limit of 35 percent may have to be assumed unless some auxiliary heating of the RAP takes place.

This method helps to minimize air pollution, which is a large concern with hot-mix recycling. The lower percent RAP which can be used is a drawback as compared to the drum mix plants though.

DRUM MIX PLANTS

In a conventional drum mix plant, virgin aggregate is first proportioned at the cold feed, then dried, heated and mixed with the asphalt cement in a drum which has a burner at one end. The aggregate enters the drum at the burner end and is exposed to very high temperatures from the flame and hot gases. Initial attempts of hot-mix recycling in these conventional plants resulted in the RAP being exposed to these very high temperatures and gases at the burner end of the drum. This caused large pollution problems due to high emission levels. The aged asphalt cement was also burned and hardened by this.

A number of methods have been developed to handle this problem and produce a good recycled mix. Some of these methods are the pyrocone system, the drum in a drum system and the center feed system.

In the pyrocone system, control of the heat transfer rate at the burner end of the drum to prevent overheating of the RAP, is provided. The system utilizes a cylindrical combustion chamber with a conical heat shield ("pyrocone"). This unit is placed between the burner and the drum. This system does work, however the pyrocones are expensive and the productivity is limited.

In the drum in a drum system, a dual drum at the burner end is created. The virgin aggregate enters through the inner drum and comes into direct contact with the flame and hot gases. The RAP enters through the space between the two drums. In this way it is shielded from the flame and hot gases. The RAP then has a chance to start heating up from contact with the inner drum. The RAP, new aggregate and asphalt cement are mixed in the lower portion of the drum.

The center feed drum mix plant is probably the most popular of the drum mix plants. In this plant, the new aggregate enters the drum at the burner end, while the RAP enters near the midpoint of the drum. At this point the RAP can be mixed with the new aggregate without being damaged by the flame and very hot gases of the burner. This is because the new aggregate acts as a veil between the burner and the RAP. The new asphalt cement is added just downstream of the

RAP entry point. The mixing is then completed in the lower half of the drum.

The center feed plants are made even more effective by lengthening of the drum. This allows the RAP to be further protected from burning and provides a longer resident time for heating and mixing. These plants can handle up to 70 percent RAP in the mix.

LAYDOWN AND COMPACTION

The laydown and compaction of recycled hot-mix asphalt concrete does not require any different equipment than with new mixes. A properly designed recycled hot-mix should not behave any differently than new mixes at this point in time.

CONCLUSION

The equipment considerations for hot-mix recycling presented in this chapter show that all of the equipment needed is currently available. There are not a large number of additional pieces of equipment that are required.

Milling machines probably represent the largest equipment investment needed in the business. Existing plants can be modified to handle recycled mixes at reasonable costs. New plants can be purchased which are designed to be more efficient in handling the recycled mixes based on economic considerations. These plants and even modified plants can still handle both recycled and new mixes.

There appears to be no significant equipment constraints which would slow down the spread or popularity of hot-mix recycling.

CHAPTER SEVEN

THE ECONOMICS OF ASPHALT HOT-MIX RECYCLING

INTRODUCTION

Cost is a major consideration when choosing the hot-mix recycling process. This chapter will present the economic factors which must be considered. The main emphasis of this chapter will be to show the comparison of the economics and energy usage of the hot-mix recycling process to the conventional asphalt overlay.

The cost advantages of hot-mix recycling have allowed numerous Departments of Transportation to stretch out their limited budgets to cover more rehabilitative work. The Florida Department of Transportation (FDOT) showed an average of a 25% cost savings when using hot-mix recycling.

While it is not always easy to determine the exact cost savings, estimates can be made. The general information presented in this chapter can be used by the engineer to help estimate the potential or actual cost savings on an asphalt hot-mix recycling project. The results of cost and energy savings from a FDOT recycling project (SR-25 project) will be presented as an example.

ENERGY SAVINGS

Energy conservation is an item that has become very important is this time of rising energy prices. Hot-mix recycling can save substantial amounts of energy when compared to conventional asphalt overlays or reconstruction. In determining energy savings, many factors must be considered for each project. Some of these factors include:

1. Amount of virgin aggregate required
2. Virgin aggregate haul distance
3. Amount of new asphalt cement required
4. Asphalt cement haul distance
5. Pavement removal method
6. Pavement crushing method
7. Haul distance from the project site to the nearest pavement disposal site
8. Haul distance from the project site to the crushing/mixing plant
9. Type of mixing plant
10. Moisture content of the RAP and virgin aggregate

The various haul distances listed above play a very significant role in determining the overall energy savings on any particular project. As the distance the new aggregate must be hauled becomes increasingly greater than the distance between the project site and the mixing plant, the advantages of hot-mix recycling will increase to a significant extent. The reverse will be true as well. As the distance between the mixing plant and project site becomes increasingly greater than the distance between the mixing plant and the source of new aggregate, the advantages of hot-mix recycling will reduce significantly.

Tables 8, 9 and 10 show the estimated energy consumption for both a conventional hot-mix overlay and a recycled hot-mix. This data was compiled by Mr. K. Murphy of FDOT based on the SR-25 hot-mix recycling project in Florida. These tables are meant to provide a general example of how energy savings could be calculated. These calculations would have to be modified to meet the specifics of a particular project an engineer may be interested in though.

Table 8 shows the estimated energy consumption for conventional hot-mix overlay. Table 9 shows similar information for the recycled hot-mix. Table 10 then shows a summary of the energy savings based on the figures developed in Tables 8 and 9.

This project showed an overall energy savings of 45.8 percent for the recycled mix as compared to the conventional overlay. These savings were highly dependent upon the haul distances involved and the materials which were conserved.

TABLE 8

ESTIMATED ENERGY CONSUMPTION FOR CONVENTIONAL HOT-MIX OVERLAY

(FROM RUTH-SCHWEYER ASSOCIATES, INC., 1980)

1. Aggregate Production and Hauling	BTU/Ton
A. Type S-1 Surface Course	
50% Crushed Stone @ 70,000 BTU/Ton	35,000
25% Crushed Stone Screenings @ 70,000 BTU/Ton	17,500
25% Local Sand @ 15,000 BTU/Ton*	3,750
Delivery to Plant:	
Crushed Stone, (106 mi)(0.5)(1360 BTU/Ton Mi)	72,080
Screenings, (80 mi)(0.25)(1360 BTU/Ton Mi)	27,200
Total for Type S-1 Surface Course	155,530
B. Type III Leveling Course	
20% Crushed Stone @ 70,000 BTU/Ton	14,000
55% Crushed Stone Screenings @ 70,000 BTU/Ton	38,500
25% Local Sand @ 15,000 BTU/Ton*	3,750
Delivery to Plant:	
Crushed Stone, (106 mi)(0.2)(1360 BTU/Ton Mi)	28,832
Screenings, (80 mi)(0.55)(1360 BTU/Ton Mi)	59,840
Total for Type III Leveling	144,922
C. Asphalt Cement	
Manufacturing	587,500
Delivery to Plant:	
Asphalt Cement, (192 mi)(1960 BTU/Ton Mi)	376,320
Total for Asphalt Cement	963,820

* - includes energy consumption to stockpile

TABLE 8 (CONTINUED)

2.	Asphalt Concrete Materials	BTU
	A. Type S-1 Surface:	
	Asphalt Cement, 6.0%, 28,171 Tons of Hot-mix	
	(0.06)(28,171)(963,820 BTU/Ton)	1,629,106,000
	Aggregate, 94.0%	
	(0.94)(28,171)(155,530 BTU/Ton)	4,118,549,000
	B. Type III Leveling:	
	Asphalt Cement, 7.0%, 9,727 Tons of Hot-mix	
	(0.07)(9,727)(963,820 BTU/Ton)	656,255,000
	Aggregate, 93%	
	(0.93)(9,727)(144,922 BTU/Ton)	1,310,980,000
	Total Energy for Aggregate and Asphalt	7,714,890,000
3.	Plant Operation for Conventional Asphalt Concrete	
	A. Fuel Consumption, 2.5 gal. diesel fuel/ton hot-mix	
	(2.5)(37,898 Tons)(139,000 BTU/Ton)	13,169,555,000
	B. Electricity:	
	$\frac{(\$0.14/\text{Ton})(37{,}898\ \text{Tons})(3415\ \text{BTU/KWH})}{(\$0.045/\text{KWH})}$	402,645,000
	Total Energy for Plant Operations	13,572,200,000
4.	Field Operations for Conventional Asphalt Concrete	
	A. Haul, Hot-mix	
	$\frac{(8\ \text{miles})(1723\ \text{Trips})}{4.25\ \text{mpg diesel fuel}}$	3244 gals.
	B. Compaction: Three Rollers @ 2 gal./hr.	
	(3)(2)(240 hrs)	1440 gals.

TABLE 8 (CONTINUED)

4. (continued)

C. Paving Machine: @ 3.5 gal./hr.

(3.5)(240 hrs)	840 gals.
Total Diesel Fuel	5524 gals.

Total Energy for Field Operations:

(5524 gals.)(139,000 BTU/gal.)	767,836,000 BTU

5. Shoulder Material — BTU

A. Local Sand, Excavate and Stockpile:

(15,000 BTU/Ton)(23,620 Tons)	354,300,000

B. Haul Trucks:

(8 miles)(2437 Trips)(139,000 BTU/gal) / 4.25 mpg diesel fuel	637,593,000
Total Energy for Shoulder Material	991,893,000

6. Summary: Energy Consumption, Conventional Asphalt Concrete

Operation	Total Energy, BTU	BTU/Ton	Percent Energy Requirement
A. Materials	7,714,890,000	203,600	33.5
B. Plant Operations	13,572,200,000	358,120	58.9
C. Field Operations	767,836,000	20,260	3.3
D. Shoulder Work	991,893,000	-	4.3
Totals	23,046,819,000	581,980	100.0

TABLE 9

ENERGY CONSUMPTION FOR RECYCLED HOT-MIX

(FROM RUTH-SCHWEYER ASSOCIATES, INC., 1980)

1.	Milling 33.35 Lane-Miles of Existing Pavement, 2.5 inches	
	A. Milling Machine:	
	(30 days)(200 gal diesel fuel/day)	6000 gal.
	B. Haul Trucks: (8 miles)(1182 Trips) / 4.25 mpg of diesel fuel	2225 gal.
	Total Diesel Fuel Consumption	8225 gal.
	Total Milling Energy:	
	(8225)(139,000 BTU/gal)	1,143,275,000 BTU
2.	Recycled Asphalt Concrete Materials, 3 inches,(35,530 Tn)	
	A. Manufacture Asphalt Emulsion (3.7% used in mix):	
	(506,100 BTU/Ton)(0.037)(35,550)	665,324,000
	B. Delivery of Asphalt Emulsion to Plant:	
	(192 miles)(1960 BTU/Ton mile)(35,530)(0.037)	494,714,000
	C. Local Sand (34.1%), Excavate and Stockpile:	
	(15,000 BTU/Ton)(35,550)(0.341)	181,736,000
	Total Asphalt and Aggregate Energy (BTU)	1,341,774,000
3.	Plant Operations for Recycled Asphalt Concrete(35,530 Tn)	
	A. Fuel Consumption, 1.8 gal diesel fuel/ton hot-mix:	
	(1.8)(35,530)(139,000 BTU/gal)	8,889,606,000
	B. Electricity:	
	($0.14/ton)(35,530)(3415 BTU/KWH) / ($0.045/KWH)	377,486,000
	Total Energy for Plant Operations	9,267,092,000

TABLE 9 (CONTINUED)

4. Field Operations for Recycled Concrete (35,530 tons)

A. Haul: hot-mix, plant to paver and return

(8 miles)(1615 trips)/4.25 mpg diesel fuel — 3040 gal.

B. Compaction: three rollers @ 2 gal/hr

(3)(2)(240 hrs) — 1440 gal.

C. Paving Machine:

(3.5 gal/hr)(240 hrs) — 840 gal.

Total Diesel Fuel — 5320 gal.

Total Energy for Field Operations:

(5320)(139,000 BTU/gal) — 739,480,000 BTU

5. Summary: Energy Consumption of Recycled Mix

Operation	Energy, BTU	BTU/Ton	Percent Energy Requirement
A. Milling	1,143,275,000	32,178	9.2
B. Materials	1,341,774,000	37,765	10.7
C. Plant Operations	9,267,092,000	260,824	[illegible]
D. Field Operations	739,480,000	20,813	5.9
Totals	12,491,621,000	351,580	100.0

TABLE 10

SUMMARY OF ENERGY SAVINGS (SR-25 PROJECT)

(FROM RUTH-SCHWEYER ASSOCIATES, INC., 1980)

Operation for SR-25 Project	Energy, BTU for 33.35 Lane Miles: Conventional Overlay	Recycling
Milling and Materials	7,714,890,000	2,485,049,000
Plant Operations	13,572,200,000	9,267,092,000
Field Operations	1,759,729,000	739,480,000
Totals	23,046,819,000	12,491,621,000

Operation for SR-25 Project	Energy Savings: BTU	% For Each Operation	% of Total
Milling and Materials	5,229,841,000	67.8	49.5
Plant Operations	4,305,108,000	31.7	40.8
Field Operations	1,020,249,000	58.0	9.6
Totals	10,555,198,000	45.8	100.0

COST SAVINGS

Saving energy is a large part of cost savings in a hot-mix recycling project. It is not the only factor which must be considered though. The entire hot-mix recycling process must be reviewed and evaluated based on other cost sensitive elements as well.

The overall economic gain for a recycling project can be analyzed through:

1. The reuse of milled or processed RAP.

2. The savings in cost for new materials (asphalt cement and aggregate).

3. The reduction in hauling costs if it is possible to schedule trucks to carry milled material to the plant or stockpile and recycled hot-mix back to the project site.

4. The savings that can occur by locating high production portable plants nearby the project site to reduce haul distances.

The existing pavement materials have a total dollar value. This total dollar value will fluctuate with the prices and availability of the asphalt cement and aggregate. The total dollar value of this material must then have reclaiming costs subtracted from it to provide the actual dollar value. Most agencies make it part of their recycling contracts that the RAP will belong to the contractor. The contractor must account for the actual dollar value of the RAP in his bid. The lower the value the contractor places on this RAP, the higher his bid will be. This would allow for a larger profit margin but would also mean that if bidding in the area is competitive, he could lose the bid.

The savings in cost for new materials is reflected in the percentage of RAP used in the recycled mix. The higher the percentage of RAP, the greater the savings. The contractor who has the drum mix plant can produce a mix with a greater percentage of RAP than can the contractor with the batch plant. This could give him a distinct advantage during bidding.

Hot-mix recycling offers the potential to schedule the trucks on the project to haul RAP (mainly in the case where milling is used) to the plant and then haul recycled hot-mix back to the project site. This would require coordination of both of these operations. This is very possible to do if the milling operation works from one half to one day ahead of the paving operation. This can result in a cost savings in hauling these materials.

It has already been discussed that the haul distances between the plant and the project site, as compared to between the plant and source of new aggregate, plays a significant role in the advantages of hot-mix recycling. If a high production portable plant can be placed nearby to the project site, the potential for large savings in hauling costs goes up significantly. The actual savings will depend on the particular site in question.

All of these items added together represent a rather significant potential cost savings for hot-mix recycling. Table 11 is presented to show a sampling of cost and energy savings from various actual recycling projects. These savings are based on data provided in the Federal Highway Administration (FHWA) Demonstration Project DP-39-15 Report and as found in the FDOT SR-25 project.

Table 11 shows that there can be considerable variation in cost and energy savings between various projects. Variations are to be expected when the factors of job location, hauling costs, mix design, efficiency of the plant and paving operation, competitiveness in bidding, and procedures used to evaluate cost and energy savings, are taken into account.

TABLE 11

COST AND ENERGY SAVINGS FOR HOT-MIX RECYCLING PROJECTS

Project Size, Tons	Cost Savings ($/Ton)	Total Cost Savings,$	Energy Savings BTU/Ton	Total Energy Savings,BTU
2.52 E4	4.02	1.01 E5	-	-
4.79 E4	3.05	1.46 F5	7.06 E4	3.38 E9
6.07 E4	0.98	5.98 E4	2.50 E3	1.52 E8
4.21 E4	3.29	1.39 E5	-	-
1.07 E5	5.16	5.53 E5	2.67 E4	2.86 E9
3.55 E5*	8.43	2.99 E5	2.57 E5	10.56 E9

* SR-25 project values were high due to short haul distances.

CONCLUSION

The cost and energy savings of a particular project may be difficult to calculate due to the number of assumptions which must be made in the calculations. What is not hard to see is the fact that hot-mix recycling does have significant potential for saving both energy and total cost on a project. The end results for the projects listed in Table 11 can bear that out.

This chapter has attempted to highlight some of the more important factors which must be considered in the hot-mix recycling process. The two items which have the most significant impact on the overall savings potential are the haul distances involved and the percentage of RAP in the mix. By concentrating on these areas, it is possible to enable the engineer to make some rough economic calculations when choosing a rehabilitation method.

CHAPTER EIGHT

CONCLUSION

This paper has looked at the various key elements of the asphalt hot-mix recycling process. A number of observations concerning the entire process have been made.

The first of these items is that the asphalt hot-mix recycling process should be viewed as one of a number of rehabilitative alternatives. The advantages and disadvantages of the various rehabilitative alternatives, including hot-mix recycling, must then be kept in mind when choosing the best alternative for the given situation.

When hot-mix recycling has been chosen as the rehabilitative method for the particular project, obtaining representative samples of the materials involved then becomes crucial. Recycling projects can be expected to exhibit variability in material properties. To quantify this variability, the existing construction and maintenance records need to be reviewed and then a sampling plan needs to be developed. The plan must take into account the information found in the original construction and maintenance records and then should select sampling locations by means of a random method. This characterization of the existing materials will then become the basis of the mix design process.

Recycled hot-mixes can be designed ith confidence once the existing materials are characterized. There are standard procedures in existence which have proven themselves to be effective. The mix design methods as published by The Asphalt Institute are the standard. Many small variations to account for local practices and materials are possible though. The mix design procedures presented in this paper point out some of these variations. The mix design should aim for allowing the highest percentage of RAP as practical.

The use of recycling agents is a cause of concern in some states. While various states and organizations have developed some guidelines for them, no American national standards exist at the present time. The ASTM is presently finalizing standards on recycling agents. Establishment of these standards could do a lot to help boost the confidence of various agencies around the country in the use of recycling agents. Recycling agents allow for the greatest flexibility in the design of recycled hot-mix.

Quality control measures are very important in hot-mix recycling. Steps such as FDOT have taken in establishing an end-result viscosity specification are very important. This can guard against all kinds of problems from improper asphalt cement blending and poor recycling agents, to processing deficiencies such as damage by overheating. Sampling at the plant and after the recycled mix has been laid and compacted are very important quality control measures.

There are no major equipment considerations which should stand in the way of increased hot-mix recycling. Milling machines are the only new independent pieces of equipment used to a large degree. Existing plants can be modified to produce recycled mixes. Some of the newer plants are designed right from the start to handle both new and recycled mixes. Drum mix plants have the benefit of being able to produce recycled mixes with larger percentages of RAP than can be produced in batch plants.

The exact economic benefits of hot-mix recycling can be difficult to determine due to the large number of assumptions which must be made in calculating costs and choosing the appropriate alternatives to compare. The haul distances involved as well as the percentage of RAP to be used in the mix will be the key points to consider when looking at costs though. As the distance between the source of new aggregate and the plant becomes increasingly larger than the distance between the plant and the project site, the advantages of hot-mix recycling increase significantly. The larger the percentage of RAP in the mix, the greater the cost savings can be as well. High production portable plants, which can be located near the project site, have a high potential for providing significant cost savings in hot-mix recycling.

When all of these items are looked upon as a whole, the advantages of hot-mix recycling greatly outweigh the disadvantages. It is easy to understand why some states such as Florida and Wisconsin (to name only two) have fully endorsed hot-mix recycling as a cost effective and technically sound pavement rehabilitative method. The trend established by FDOT in combining their asphalt specifications to include both recycled and new mixes has gone a long way towards standardizing hot-mix recycling.

It is a bit harder to understand why all states have not done this. Perhaps one good reason may be that some states are waiting to see the long term analysis of life cycle and costs associated with hot-mix recycling. Ten year figures on large quantities of recycled mixes should start to become available within the next few years.

Positive results published from this data, along with the once again upwardly climbing prices for oil, should combine to push hot-mix recycling to new heights. The future of hot-mix recycling looks to be very bright.

BIBLIOGRAPHY

Beaty, R. W. and Binz, L. V., "Hot-Mix Recycling of Asphalt Pavements: An Overview", Rural and Urban Roads, July, 1980, p. 60.

Betenson, Wade B., Recycling Asphalt Pavements (FHWA-DP-39-31), Report for FHWA Demonstration Projects Division By Utah Department of Transportation, Salt Lake City, Utah, 1980.

Betenson, Wade B., "UDOT's 5-Year Probe of Hot-Mix Recycling", Rural and Urban Roads, July, 1980, p. 30.

Brown, Elton R., Evaluation of Properties of Recycled Asphalt Concrete Hot-Mix (Technical Report GL-84-2), Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.,1984.

Brown, Elton R., Hot-Mix Recycling at Pope AFB, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1980.

Canessa, William, The Chemical Aspects of Asphalt Pavement Recycling Affecting Engineering Considerations, Golden Bear Division, WITCO Chemical Corporation, Oildale, Ca., Reprint of Prepared Discussion for Presentation at the Annual Meeting of the Association of Asphalt Paving Technologists, Denver, Co., February 19-21, 1979.

Caterpillar, Venturi-Mixer, QEHQ 0076 (1-85), U.S.A., 1985.

Coyne, L. D., Kari, W. J. and Santucci, L. E., Hot-Mix Recycling of Asphalt Pavements, Asphalt Division, Chevron U.S.A., Inc., Presented at the Annual Meeting of the Association of Asphalt Paving Technologists, Denver, Co., 1979.

Davidson, Donald D. and Escobar, Steven J., Role of Recycling Agents in the Restoration of Aged Asphalt Cements, Golden Bear Division, WITCO Chemical Corporation, Oildale, Ca., Reprint of Paper Prepared for Presentation at the Annual Meeting of the Association of Asphalt Paving Technologists, Denver, Co., February 19-21, 1979.

Eagle Crusher Company Inc., Eagle Recycling Plants and Systems, Galion, Ohio, 1986.

Edge, Duane E., "Mix Design Formulas for Recycled Hot-Asphalt Plant Mixtures", Civil Engineering - ASCE, December, 1981, p. 63.

Epps, J. A., Holmgreen, R. J., Little, D. N. and Terrel, R. L., Guidelines for Recycling Pavement Materials, National Cooperative Highway Research Program Report 224, Transportation Research Board, Washington, D.C., 1980.

Epps, Jon A. and Little, Dallas N., Evaluation of Certain Structural Characteristics of Recycled Pavement Materials, Prepared for Presentation to the Association of Asphalt Paving Technologists, Louisville, Ky., February 18-20, 1980.

Goldstein, Gary, "Pavement Recycling", Civil Engineering-ASCE, September, 1984, p. 54.

Kallas, Bernard F., Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete (RR-84-2), The Asphalt Institute, College Park, Md., 1984.

Kari, W. J. and Santucci, L. E., Hot-Mix Recycling: Equipment, Construction, Design, Results, Chevron U.S.A., Inc., Asphalt Division, Presented at the Eighteenth Paving Conference, University of New Mexico, Albuquerque, N.M., 1981.

"New Plants Increase Effectiveness of Asphalt Pavement Recycling", Better Roads, December, 1981, p. 16.

"Old Asphalt Sees New Youth as Recycling Comes of Age", ENR, March 23, 1978, p. 54.

Potts, Charles, "Florida's Diligent Move Into Hot-Mix Recycling", Rural and Urban Roads, July, 1981, p. 28.

"Recycling Comes of Age", Construction Contracting, May/June, 1981, p. 32.

"Recycling/Rejuvenating Aged Asphalt Pavements Using Hot-Mix Process", Better Roads, January, 1982, p. 10.

Ruth, Byron E., Hot-Mix Recycling Construction Methods, Quality Control, Costs and Energy (Session 3 Paper 2), National Symposium on Binder Economy and Alternate Binders in Road and Building Construction, 1981.

Ruth-Schweyer Associates, Inc., Guidelines For Hot-Mix Recycling of Asphalt Pavements, Report Prepared for the State of Florida, Department of Transportation, 1980.

State of Florida, Annual Report on Energy, Aggregate, and Dollar Savings in Asphalt Pavement Recycling, Department of Transportation, May 1, 1980 - September 30, 1981.

State of Florida, Asphalt Plant Technician Certification Study Guide, Department of Transportation, Tallahassee, Fl., 1986.

State of Florida, Standard Specifications for Road and Bridge Construction, Florida Department of Transportation, Tallahassee, Fl., 1986.

State of Florida, Hot-Mix Recycling Project 37120-3423 File, Department of Transportation, Bureau of Materials and Research, Gainesville, Fl., 1986.

Strand, D. L., "WisDOT Recycling Booms in '80 - Thanks to the Lessons of '79", Rural and Urban Roads, March, 1981, p. 26.

Strand, D. L., "WisDOT Recycling Goes State-Wide", Rural and Urban Roads, July, 1980, p. 42.

The Asphalt Institute, Asphalt Hot-Mix Recycling (MS-20), Second Edition, The Asphalt Institute, College Park, Md., 1986.

Transportation Research Board, Proceedings of the National Seminar on Asphalt Pavement Recycling, Transportation Research Record 780, National Academy of Sciences, Washington, D.C., 1980.

Zuehlke, G. H., Recycled Bituminous Pavements, State of Wisconsin, Department of Transportation, Correspondence/Memorandum, Madison, WI., February 22, 1980.

Zuehlke, G. H., Recycled Bituminous Pavements, Design of Mixture Proportions, State of Wisconsin, Department of Transportation, Correspondence/Memorandum, Madison, WI., October 1, 1981.

END

10-87

DTIC